Observations and predictions of eclipse times by astronomers in the pre-telescopic period.

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Observations and Predictions of Eclipse Times by Astronomers in the Pre-Telescopic Period

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Abstract

Eclipses of the Sun and Moon are among the most impressive of celestial events. It is therefore unsurprising that they have played an important role in the astronomy and astrology of most early cultures. Many hundreds of references to eclipses are found in the writings of the chroniclers and astronomers of the pre-telescopic world. In particular, the astronomers of Babylon, Ancient Greece, the Islamic Near East, Later Medieval and Renaissance Europe, China, and Japan, recorded a large number of observations and predictions of the time of an eclipse. The present study contains an extensive compilation of all known timed reports of eclipse observations and predictions made by astronomers in the pre-telescopic period.

By performing a basic analysis of the recorded times, it has been possible to trace the gradual development of the techniques used by the astronomers to observe and predict eclipses. In order to conduct this analysis, it has been necessary to investigate a number of other problems including the dating of damaged observational accounts, the units of time used by the early astronomers, and the methods by which the Babylonians predicted eclipses. Many of these questions have not previously been answered. Therefore, the results of this study provide important information regarding the astronomies of these early cultures.

Preface

The research presented in this study was undertaken between October 1995 and July 1998 under the supervision of Professor F. R. Stephenson. No part of this work has previously been submitted for a degree either in this or any other university. A significant part of the material presented in this thesis has previously been published in the following papers:

- J. M. Steele, "Babylonian Predictions of Lunar and Solar Eclipse Times", *Bulletin of the American Astronomical Society*, 28 (1996), 1305.
- J. M. Steele and F. R. Stephenson, "Lunar Eclipse Times Predicted by the Babylonians", *Journal for the History of Astronomy*, 28 (1997), 119–131.
- J. M. Steele, "Solar Eclipse Times Predicted by the Babylonians", *Journal for the History of Astronomy*, 28 (1997), 131–139.
- J. M. Steele, F. R. Stephenson and L. V. Morrison, "The Accuracy of Eclipse Times Measured by the Babylonians", *Journal for the History of Astronomy*, 28 (1997), 337–345.
- J. M. Steele and F. R. Stephenson, "Astronomical Evidence for the Accuracy of Clocks in Pre-Jesuit China", *Journal for the History of Astronomy*, 29 (1998), 35–48.
- J. M. Steele, "Predictions of Eclipse Times Recorded in Chinese History", *Journal for the History of Astronomy*, 29 (1998), 275–285.
- J. M. Steele, "On the Use of the Chinese *Hsuan-ming* Calendar to Predict the Times of Eclipses in Japan", *Bulletin of the School of Oriental and African Studies*, 61 (1998), 527–533.
- J. M. Steele, "The Accuracy of Babylonian Observations of Lunar Sixes", *Astronomy and Geophysics*, in press.
- J. M. Steele and F. R. Stephenson, "Eclipse Observations made by Regiomontanus and Walther", *Journal for the History of Astronomy*, in press.
- J. M. Steele, "The Latest Dated Astronomical Observation from Babylon", in A. R. Millard (ed.) *Archaeological Sciences '97*, in press.
- J. M. Steele, "A Re-analysis of the Eclipse Observations in Ptolemy's *Almagest*", *Centaurus*, submitted.

Acknowledgements

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There are many people, both in Britain and abroad, who have generously given me the benefit of their time and expertise during the course of this study. In particular, I would like to mention Dr. John Britton, Prof. Peter Huber, Prof. Hermann Hunger, Dr. Leslie Morrison, Prof. Norbert Roughton, Prof. Nathan Sivin, and Dr. Christopher Walker. I would like to thank them all, both for many useful discussions and, in several cases, for generously supplying me with copies of their transliterations and translations of unpublished texts.

Away from work, I would like to thank all my friends from my time in Durham, particularly all of the talented musicians that I have played with every Tuesday night for the past few years. Finally, I wish to record my deepest thanks to my family for their support and for not asking me why I spend all my time reading arcane texts.

Contents

Part I

Introductory Orientations

Chapter 1

Introduction

He who attempts to penetrate into the Rose Garden of the Philosophers without the key resembles a man who would walk without feet.

— Michael Maier, *Atalanta Fugiens*, De Bry, Oppenheim, 1618, emblem xxvii

1.1 General Introduction

One of the most awe-inspiring of celestial events seen by early man must surely have been the occurrence of an eclipse of the Sun or Moon. With no apparent warning, one or two times a year, a darkness encroaches upon the bright light of the Sun or Moon; sometimes to completely cover the heavenly body, sometimes to retreat before the light is fully extinguished. To make the event more ominous, the eclipsed Moon may become a dim, blood red colour, or, in the rare event of a total solar eclipse, the day may literally turn into night during which stars become visible and the air turns cold. It is therefore not surprising that eclipses were viewed as important astrological events in many early civilizations.[1]

Many thousands of references to eclipses are found throughout history. These range from groups of astrological omens associated with the appearance of an eclipse, to non-technical descriptions of eclipse observations reported by chroniclers and other writers, to detailed technical accounts of eclipse observations and predictions made by specialist astronomers. It will be this final group of eclipse records, in particular those that include a reference to the time when the eclipse was observed or predicted, that will form the basis of the present study. Before progressing any further, however, it is necessary to remark that the group of people I have called "specialist astronomers" above are not necessarily the same as those we would think of as astronomers today. They include such groups of people as the Babylonian diviners or scribes, and the Chinese astrological and calendar officials, as well as those persons more readily identifiable as astronomers, such as Ptolemy and Tycho Brahe. I shall generally refer to all of these groups of people simply as "astronomers".

The main goal of the present study is to collect all of the known sources of observations and predictions of eclipse times made by astronomers in the pre-telescopic world, and to discover what may be learnt from the accuracy of these times regarding the techniques used in their observation and prediction. In the course of this work, however, it will be necessary to discuss a number of other topics, such as dating damaged observational accounts and the units of time used by the early astronomers, many of which have not previously been addressed in sufficient detail. Translations of many of the eclipse records discussed in this study are provided, either in the main chapters, or in the appendices. As a general rule, if reliable translations of a series of eclipse records have previously

[1]For a survey of ethnohistorical data regarding eclipses, see Closs (1989). This survey is confined to the Central American region. To my knowledge no such surveys have been made for other parts of the world.

been published by other authors then I have quoted the most relevant accounts as examples, but if translations are not available elsewhere then I have provided full translations of all the records.

Although this study is primarily historical, it does make use of computations of the circumstances of historical astronomical events based upon modern theories of lunar, solar, planetary and stellar motion. This is an example of one of the ways that the techniques of one discipline can be used to help research into another. Furthermore, as modern studies of the long-term variations in the Earth's rate of rotation have made extensive use of historical eclipse observations, the present investigation has implications for the reliability of this work. Thus there exists a circle in which science can be used to help in a historical study, and this in turn may be of some benefit to further scientific investigations.

In the remainder of the present chapter I shall provide the necessary introductory material for this study. Chapters 2 to 7 will then discuss the eclipse records found in the history of each of the following cultures: Mesopotamia, Ancient Europe, the Islamic Near East, Later Medieval and Renaissance Europe, China, and Japan. Finally, in Chapter 8, I will make some concluding remarks based upon the results from the preceding chapters.

1.2 A Survey of Astronomical Records in Pre-Telescopic Cultures

According to Aveni (1980: 3), "all developing civilizations exhibit a reverence for the sky and its contents." Whilst this may at first seem to be a somewhat bold statement, it is nevertheless borne out by the available evidence. Virtually all known cultures, both literate and pre-literate, are thought to have gazed into the heavens and to have recorded what they have seen — whether it be in written accounts, drawings, or even architectural representations. I outline the main historical cultures known to have had an interest in astronomy below:

Mesopotamia:

Mesopotamian civilization developed in the fertile crescent between the Euphrates and Tigris rivers in south-west Asia during the third millennium BC. Already by the end of this millennium, astronomy, or more correctly astrology, had become very important in Mesopotamian society, with the development of series of astronomical omens. By the Late Babylonian period (c. 750 BC), detailed astronomical records were being kept, of which a small percentage are still preserved today. These include more than a hundred records of eclipse observations and predictions. By the Seleucid period (c. 300 BC), complex systems of mathematical astronomy had been developed for predicting events such as the first visibility of the lunar crescent which marked the beginning of each month. These schemes would later be transmitted to Greece where they would form the basis of Hipparchus' astronomical theories (Toomer 1988).

Ancient Egypt:

At around the same period as the birth of Mesopotamia, Egypt also developed into a great civilization. Unquestionably, astronomy had a role in Egyptian society, for example in the development of a solar calendar at a very early period, but it is not clear to how great an extent this role was. Recently, it has become popular to suggest that the Egyptian astronomers were far in advance of their time. It has been claimed, for example, that they discovered the effects of precession several thousand years before Hipparchus (Sellers 1992), but there is precious little evidence to support these claims. Indeed, due to the very small amount of astronomical material known from Egypt (Neugebauer & Parker 1960, 1964, 1969), it is hard to make any realistic judgements regarding the astronomical achievements of this civilization. Despite the claim by Sellers (1992) that eclipses played a fundamental role in the development of Egyptian religion, no eclipse records have been found from Ancient Egypt. Therefore, Egypt will not be considered any further in this study.

Ancient Europe:

The principal Ancient European civilizations of Greece and Rome developed significantly later than their Mesopotamian and Egyptian neighbours. Nevertheless, by the end of the first millennium BC, they had become the dominant military and cultural powers in the region. Ancient Greek science has long been held up by historians of astronomy as the mark against which all other scientific achievements should be judged.[2] However, the reality is less impressive, at least in the field of Greek astronomy. As I have already mentioned, the Babylonian influence on Hipparchus and others was profound, and it is doubtful whether Greek science would enjoy the reputation it does without it. Nevertheless, works such as Ptolemy's *Almagest* are of great importance to the history of astronomy due to their influence on later cultures. The *Almagest* is one of the few sources of astronomical observations preserved from Ancient Europe.[3] Other sources include some of the histories and literary works written by, for example, Herodotus and Diodorus Siculus.

India:

Indian interest in astronomy seems to have developed in the latter half of the first millennium BC. As with virtually all Indian astronomy, this interest was almost exclusively in the development of astronomical theories; the only role of astronomy in Indian astronomy appears to have been in checking accepted parameters (Pingree 1996). Early Indian astronomy was largely based upon Mesopotamian practices, with some input from Greek developments (Pingree 1973). By the middle of the fifth century AD, the Indian astronomers had made many developments of their own, and from this period on it is possible to talk of "Indian astronomy" as its own subject. It was not until the seventeenth and eighteenth centuries AD that the works of Islamic astronomers found their way into India, and the Indian astronomers began to take an interest in the relationship between observation and theory. Thus, there are very few records of observations made by Indian astronomers before this period, and so they will not be considered any further in this study.

The Near East:

From shortly after the death of the Prophet Muḥammad in the seventh century AD, the Muslims had established a commonwealth of nations that stretched from India to Morocco and Spain. Near Eastern astronomers, in which I am including those Islamic astronomers who worked in areas as diverse as Afghanistan and North Africa, quickly assimilated much of the astronomy preserved in the writings of the Ancient Greeks, and by the ninth century AD had begun to make significant astronomical developments of their own. Among their achievements was a realization of the importance of observation in astronomy. This resulted in the construction of a number of observatories, both private and royal, which were intended to conduct extensive programmes of astronomical observation. Unfortunately, only a relatively small number of these observations are still preserved. These are, however, of considerable interest. In particular, a number of eclipse observations from the ninth to the eleventh centuries AD are extant. These have aroused considerable interest among scholars, both for their historical value, and for their potential use in studies of the Earth's rotation.

Later Medieval and Renaissance Europe:

In the period running up to the European Renaissance, elements of Islamic astronomy were transmitted to Europe through Muslim Spain. This was to provide the necessary background in which

[2]See Pingree (1992) for a discussion of the ways in which "Hellenophilia" has blinded historians of science.

[3]For the present purposes, Ancient Europe can be considered to extend to Alexandria since northern Egypt was under Roman rule at this period.

astronomers such as Copernicus and Kepler could formulate their theories of solar, lunar and planetary motion. For the first time in Europe, astronomers began to make careful observations of astronomical phenomena. The principal reason for making these observations was to test and formulate improvements to established astronomical tables.

China:

Interest in astronomy in China seems to have developed in the middle of the second millennium BC. By the eighth century BC, systematic astronomical records were being to be kept. These continue more or less uninterrupted to the present day, despite the many changes of ruling dynasty. Due to its relative isolation in its formative years, Chinese astronomy differed significantly from that in the western world. In particular, in China, astronomy was primarily the activity of the bureaucratic state, rather than of priests or scholars as in the west. This was a two-edged sword, for it provided a strong motivation for astronomical advancement, but also led to the political manipulation of astronomers and their observations. With the arrival of the Jesuit missionaries in the seventeenth century AD, Chinese astronomy underwent a profound change. The Jesuits brought with them western astronomical theories which quickly became incorporated into Chinese astronomy. Nevertheless, the traditional role of astronomy in Chinese society continued until the establishment of the Republic in AD 1911.

Korea:

The country of Korea was established in about AD 670 when the kingdom of Silla subjugated its two neighbours, Paekche and Koguryo. The earliest history of Korea, the *Samguk Sagi*, describes the period from legendary times down to AD 935. Like most Korean books, it is written in Chinese, for Korean culture at this and later periods was strongly influenced by China. In particular, Korean astronomy was based wholly upon that practiced in China, even to the extent of the adoption of the Chinese calendar. The *Samguk Sagi*, along with later histories such as the *Koryo-sa*, contains a number of astronomical records, including many eclipses. However, in none of these records is either the observed or predicted time of the eclipse given (Stephenson 1997b). Therefore, these records will not be considered further in this study.

Japan:

Japanese civilization developed at a similar period to that in Korea. As with its neighbour, Japanese culture, and in particular its astronomy, was profoundly influenced by that of China. However, from the end of the ninth century AD, Japan entered a state of semi-isolation. It was not until the fifteenth century AD that Japan began again to experience any significant foreign influences on its society. Nevertheless, Chinese astronomical practices continued to dominate in Japan throughout this period of separation. Many tens of Japanese works contain records of astronomical events (Kanda 1935). Among them are a number of eclipse records, many of which contain the expected time of the eclipse.

Mesoamerica:

It is well known that the Mayan and other Mesoamerican civilizations developed a very advanced astronomy. This included very accurate calendar schemes, and mechanisms for making predictions of, for example, eclipses and planetary visibilities (Aveni 1980). Unfortunately, however, our understanding of Mayan astronomy is severely hindered by the small amount of material available for study; only four Mayan books survived the Spanish conquest, the others having been destroyed because they were believed to be involved with the worship of the devil (Aveni 1996). It is believed that one of the surviving Mayan works, now known as the Dresden Codex, contains a table for predicting solar eclipses (Bricker & Bricker 1983), but its exact workings are not clear. No written records of either observations or dated predictions are known, and so Mesoamerican astronomy will not be considered any further in this study.

It will be clear from my discussion above that there are three basic traditions of astronomy in the world: a "western heritage", founded upon the astronomy of Mesopotamia, that may be traced though Ancient Greek, Indian and Islamic astronomy up to the astronomers of the European Renaissance; an "eastern heritage" of astronomy developed in China and adopted in Japan and Korea; and a "New World heritage" for the astronomy of the Mesoamerican cultures. Astronomical records are only preserved from the first of these two cultures, and so these will form the basis of the present study. It should be noted, of course, that the division into Eastern and Western, or Mesopotamian and Chinese, heritages is in some ways artificial. It implies that these two traditions developed independently which, although generally true, is not necessarily the full story. For cross fertilization of astronomical knowledge did occur — most notably between the Indian, Islamic and Chinese astronomers. Nevertheless, it will be useful to utilize this division in the present study.

1.3 Causes of Eclipses

Before it is possible to describe the formation of eclipses, it is necessary to make some remarks regarding the various systems used for keeping track of time. There are three main time systems: terrestrial time (TT), universal time (UT), and local time (LT). Terrestrial time is defined by the motion of the Moon and planets. It is an invariant time system. Universal Time is defined by the rotation of the Earth. However, since the Earth's rotation is slowing down due to the effects of tidal friction and other causes, the length of the mean solar day is changing, and so universal time is a non-constant time system. For example, about two thousand years ago, the mean solar day was about 0.05 seconds shorter than today. This results in a cumulative clock error between an ideal clock and one measuring time by the Earth's rotation of several hours. This clock error is equal to the difference between terrestrial time and universal time (in the sense TT-UT), and is known as ΔT. Like universal time, local time is also defined by the solar day, with the additional condition that midday is when the Sun is at its highest point in the sky. Local times can therefore be converted to universal times by adjusting for the geographical longitude (with reference to the Greenwich Meridian) and the equation of time. Throughout this work, all times will be given in hours and decimals.

It is well known that the Moon moves round the Earth in an approximately circular orbit. With respect to the fixed background of stars the Moon completes its revolution in an average period of 27.32166 days, known as a sidereal month. However, from our position on the Earth, the Sun also appears to circle us in a period of 365.2422 days, known as a tropical year.[4] Over the course of a sidereal month, therefore, the Sun has moved a small distance ahead of the stars, and so it takes slightly more than another 2 days for the Moon and Sun to reach conjunction. When the alignment is in the order Sun–Moon–Earth, the Moon is not visible. This is known as new Moon. However, when the alignment is Sun–Earth–Moon, the full disk of the Moon is illuminated. This is known as full Moon. The average time interval between two successive new or full Moons, known as the synodic month, is equal to 29.53059 days.

If the plane in which the Moon orbits the Earth was the same as that in which the Sun moves, one luminary would be obscured at every new and full Moon. However, the two planes are in fact inclined at an angle of about 5° to one another. The points where the paths of the motions of the two luminaries intersect are known as nodes. The average interval between successive passages of the

[4] In the following discussion, it is simpler to think of a stationary Earth orbited by the Sun.

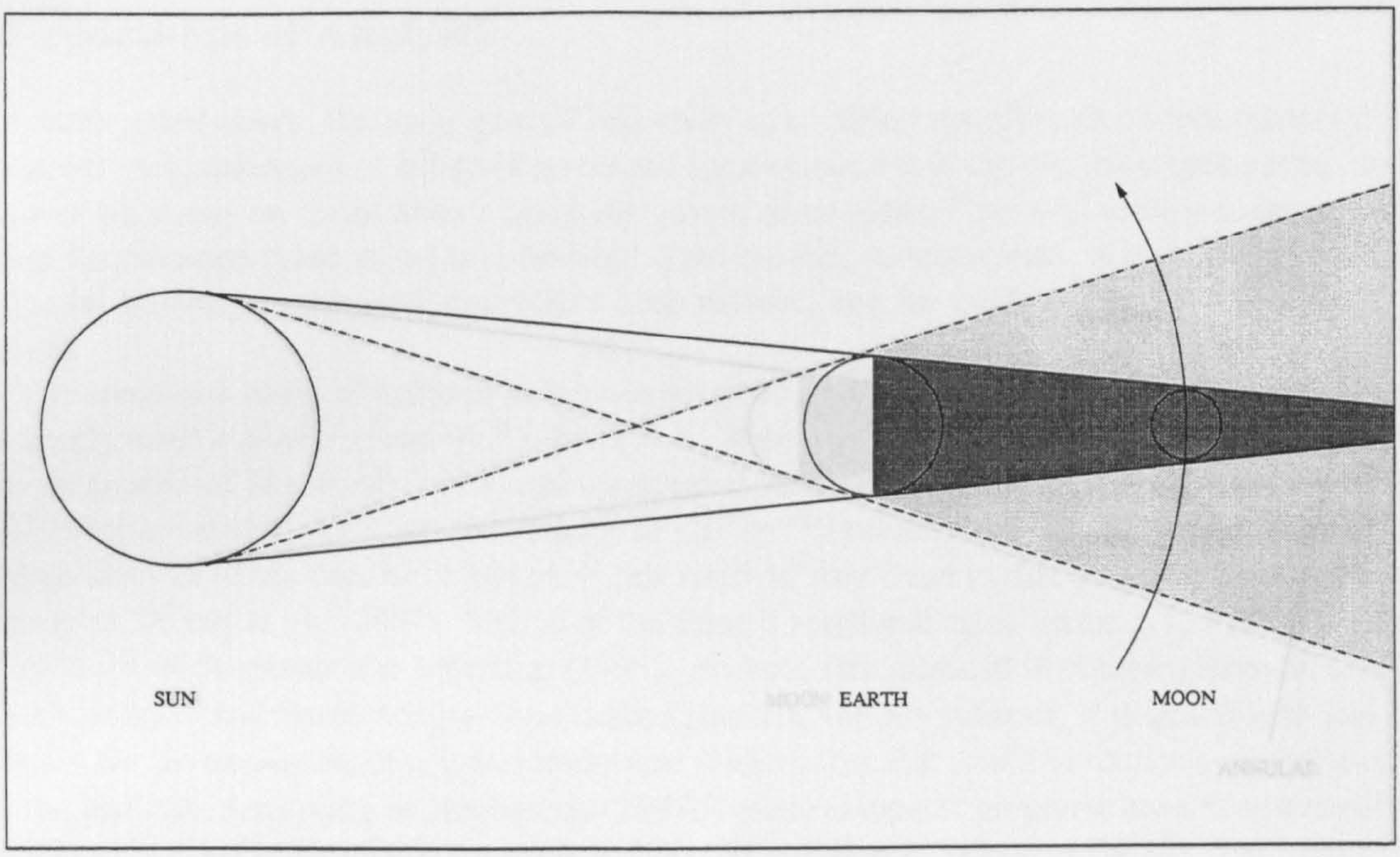

Figure 1.1: The basic mechanism of a lunar eclipse.

Moon by a given node, known as a draconitic month, is equal to 27.21222 days. Only when the Moon is near to a node will an eclipse be possible.

If the Moon is near to a node at the time of full Moon, then the Moon will enter the shadow of the Earth. This is known as a lunar eclipse. The basic mechanism of a lunar eclipse is shown in Figure 1.1. In this case the Moon passes through the light-shaded penumbral shadow until it touches the dark-shaded umbral shadow of the Earth. This is known as the moment of first contact. The Moon then continues on its path until it is completely within the umbral shadow. This moment is known as second contact. The Moon is now totally eclipsed. When the Moon's path brings it to the far side of the umbral shadow, it begins to recover its light. This moment is called third contact. Finally, the Moon completely leaves the Earth's umbral shadow, at fourth or last contact, and the eclipse is over. Whilst it is in the penumbral shadow it is sometimes possible to detect a dimming of the Moon; however, there are no firmly dated observations of penumbral eclipses from the pre-telescopic period.

If the Moon's path brings it quite close to a node at opposition, but not sufficiently close to form a total eclipse, it is possible that only part of its surface may enter the Earth's umbral shadow, the remainder passing either completely above or below. This results in a partial eclipse. Only first and last contacts are defined for a partial lunar eclipse. The magnitude of an eclipse is defined as the fraction of the lunar diameter that is eclipsed at maximum phase. Because the Moon's orbit is not exactly circular, its distance from the Earth varies. The average interval between successive closest approaches to the Earth (perigee), known as an anomalistic month, is equal to 27.55455 days. Due to this variation, the magnitude of an eclipse is not only dependent upon the Moon's path through the Earth's shadow, but also upon its distance from the Earth.

Because lunar eclipses are due to the Earth's shadow falling on the Moon's surface, they are visible from everywhere on the Earth where the Moon is above the horizon. This allows lunar eclipses to be predicted fairly successfully using cycles. Once an eclipse has occurred, another eclipse will take place when (a) the Moon is at the same phase again, and (b) the Moon is at its same position in its orbit with respect to the node. In other words, the eclipse will occur after there has been both a whole number of synodic months and a whole number of draconitic months. Although no there is no integral common multiple of these two intervals, a number of periods are close. For example,

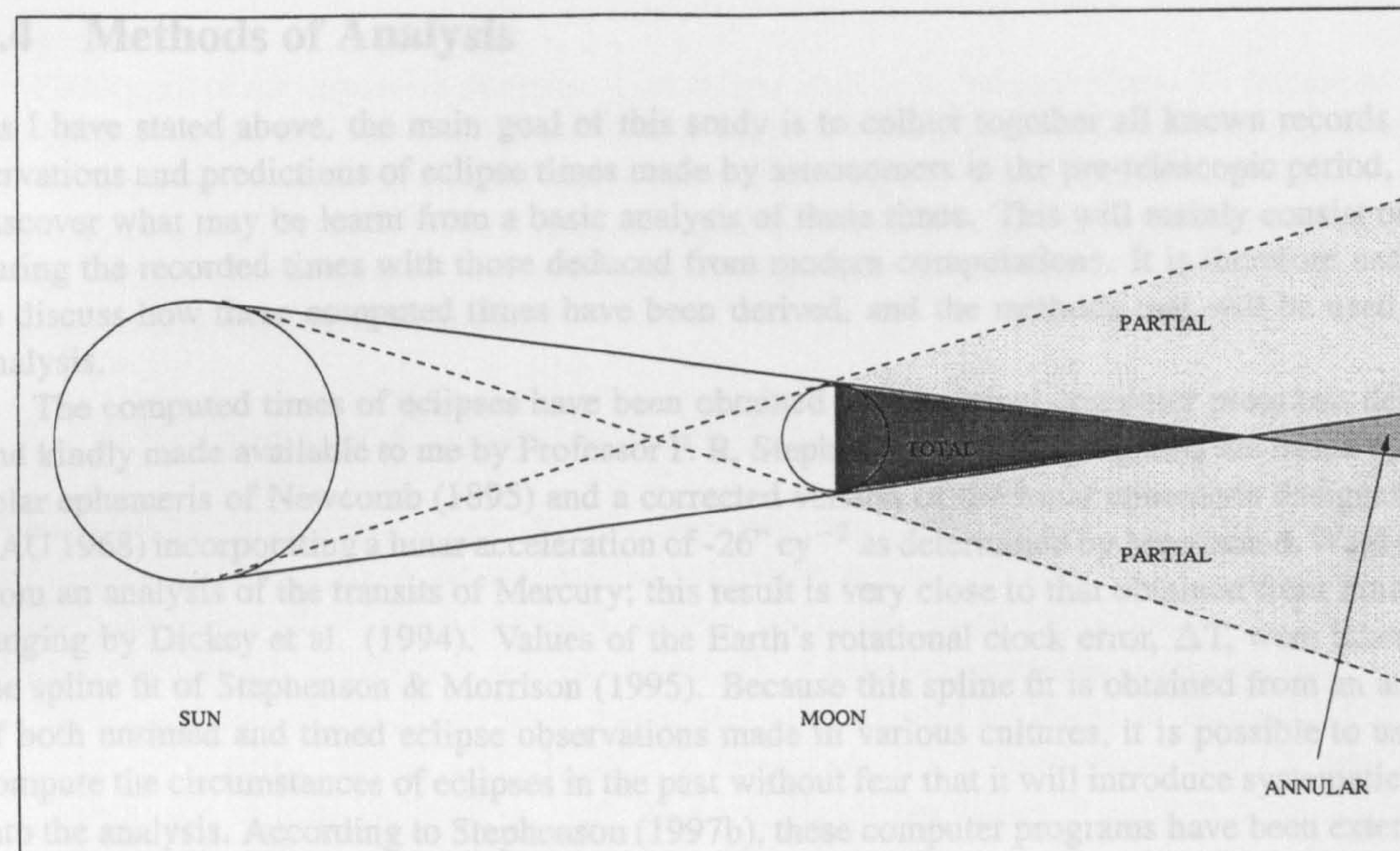

Figure 1.2: The basic mechanism of a solar eclipse.

47 synodic months is only one tenth of a day different from 51 draconitic months, and 135 synodic months is about half a day more than 146 draconitic months. The most successful of these periods is 223 synodic months, which is very close to 242 draconitic months. Furthermore, it is also very close to 239 anomalistic months.[5] This means that after 223 synodic months, lunar eclipses will recur which have similar magnitudes and durations. This period, which is equal to about 18 years $10\frac{1}{3}$ days, has become known as the "Saros", and was well known in antiquity.

Whilst lunar eclipses occur at full Moons, solar eclipses are formed when the new Moon is close to a node. The basic mechanism of a solar eclipse is shown in Figure 1.2. In a solar eclipse, the Moon passes between the Sun and the Earth, casting a shadow on the Earth's surface. However, as the Moon is much smaller than the Earth, its umbral shadow only covers a small part of the Earth's surface. Within this region a central eclipse occurs. A central eclipse may be either total, in which the whole of the Sun is obscured, or annular, in which a ring of the Sun remains bright surrounding a darkened centre, depending of the relative distances of the Sun and Moon at the time of the eclipse. Outside of the central region of a solar eclipse, a partial eclipse may be seen. Maps showing the path of the central regions of solar eclipses have been produced many authors, including, most famously, von Oppolzer (1887). It should be noted, however, that often these maps do not make sufficient allowance for the changes in the Earth's rate of rotation, and so become increasingly inaccurate at early periods.

During a solar eclipse, the shadow falls on a fraction of the Earth's surface. This means that the appearance of a solar eclipse is not the same to observers in different parts of the world. Furthermore, the time at which an eclipse occurs is not the same in different locations. This makes it much more difficult to predict a solar eclipse than a lunar eclipse as it is necessary to possess a detailed knowledge of the geometry of the Earth, Moon, and Sun, and the geographical position of the observer on the Earth's surface. Nevertheless, cycles such as the Saros can, and certainly were in antiquity, be used to predict times when solar eclipses were *possible*, and to exclude times when they were *impossible*.

[5]223 synodic months = 6585.322 days, 242 draconitic months = 6585.357 days, 239 anomalistic months = 6585.538 days (Liu & Fiala 1992).

1.4 Methods of Analysis

As I have stated above, the main goal of this study is to collect together all known records of observations and predictions of eclipse times made by astronomers in the pre-telescopic period, and to discover what may be learnt from a basic analysis of these times. This will mainly consist of comparing the recorded times with those deduced from modern computations. It is therefore necessary to discuss how these computed times have been derived, and the methods that will be used in the analysis.

The computed times of eclipses have been obtained from original computer programs designed and kindly made available to me by Professor F. R. Stephenson.[6] These programs are based upon the solar ephemeris of Newcomb (1895) and a corrected version of the lunar ephemeris designated j=2 (IAU 1968) incorporating a lunar acceleration of -26" cy^{-2} as determined by Morrison & Ward (1975) from an analysis of the transits of Mercury; this result is very close to that obtained from lunar laser ranging by Dickey et al. (1994). Values of the Earth's rotational clock error, ΔT, were taken from the spline fit of Stephenson & Morrison (1995). Because this spline fit is obtained from an analysis of both untimed and timed eclipse observations made in various cultures, it is possible to use it to compute the circumstances of eclipses in the past without fear that it will introduce systematic errors into the analysis. According to Stephenson (1997b), these computer programs have been extensively tested against other ephemerides, in particular the JPL ephemeris known as DE102, and found to be sufficiently accurate for historical purposes.

Throughout this study, the term "computed time" has been reserved for those times deduced from modern computations. Times measured by the early astronomers are called "observed" times, and times calculated by the early astronomers from their theories are called "predicted" or "calculated" times. The main tool used in this analysis is to determine the error between two of these times. The error in an observed time is the difference between the computed and the observed time (in the sense computed minus observed). Two errors may be calculated for a predicted time: the "true" error, which is the difference between the computed time and the predicted time (i.e., computed minus predicted time); and the "observed" error, which is the difference between the observed and the predicted time (i.e., observed minus predicted time). I will also use a value which I term the "accuracy" of a time. This I define as the absolute value of an error in a time.

It is necessary at this point to distinguish between the "accuracy" of an observation and the "precision" of an observation. Accuracy is a measure of the quality of an observation when compared with an assumed "true" value. Precision is a measure of the size of the unit used in the observation. For example, an observation of 13 minutes is precise to 1 minute, but if, say, the true time is 10 minutes, then it is only accurate to 3 minutes.

When there is more than one time determined by a particular astronomer or group of astronomers, I will frequently calculate the mean error and accuracy. The mean error will give an indication of any systematic error in the timings, whereas the mean accuracy will give a rough measure of the overall quality of the timings. More advanced statistics will not be used in this study since it has been repeatedly shown, for example by Swerdlow (1979), Hamilton & Swerdlow (1981), and Bielenstein & Sivin (1977), that they are at best inappropriate and at worst dangerously misleading in studying historical data.[7]

A number of stellar and planetary positions and visibilities are computed throughout this work. Planetary positions are determined using the ephemerides of Bretagnon and Simon,[8] and star positions are taken from the catalogue of Hirshfeld & Sinnott (1982), with suitable corrections for precession

[6]Occasionally minor modifications have been made to these programs by the present author.

[7]Swerdlow (1979: 529) writes: "Probability and statistics have become increasingly fashionable for dressing up history with an appearance of scientific rigor, perhaps because they can be used to prove, indifferently and in merciless detail, either the obvious or the preposterous, perhaps because numbers seem at once too impressive and too objective to question."

[8]See, for example, their discussion in Bretagnon, Simon, & Laskar (1985).

and proper motion.

Finally, all of the computed altitudes given in this work have been corrected for refraction to give the apparent rather than the true value. Similarly, when deducing local times from altitudes, all of the observed values have been corrected for refraction. These corrections have been made using the formulas given by Schaefer (1993). At the level of precision to which early astronomers made their altitude measurements, however, these corrections are virtually negligible for altitudes of more than a couple of degrees above the horizon.

1.5 A Note on the Conventions used in this Study

Throughout this work many eclipse records have been translated and dated. Unless specifically credited to another author, all of the translations published here are my own. Text contained in square brackets has been restored from damaged readings by the translator. Parentheses are used to enclose glosses added by the translator to aid reading but which have no counterpart in the original text.

Transliterations of cuneiform texts follow the style adopted by Sachs & Hunger (1988), with Sumerian given small capitals, and Akkadian in lower case italics. Romanization of Chinese characters follows the style of Wade-Giles, with the exception of the names of modern authors who have used the Pinyin rendering in their publications. Chinese text is given in italics except for names of people and places. Latin transcriptions are also given in italics except for proper names.

Throughout this work, sexagesimal numbers will often be quoted. Following Neugebauer (1955), sexagesimal numbers are transcribed using commas to separate places, and a semicolon to separate integers from fractions.[9]

Finally, many calendar systems are used in the eclipse records discussed in this work. However, I have converted all of these dates into the western calendar when discussing them. Dates up to 4 October 1582 AD are given in the Julian calendar. Those after are given in the Gregorian calendar.[10] Although all dates given in the text are in the familiar BC/AD style, for convenience dates in tables and figures often use the astronomical dating system. This is a continuous version of the Julian calendar in which year 0 corresponds to 1 BC, year -1 to 2 BC, and so on.[11]

[9]Generally therefore: a,b,c;d,e = $(a \times 60^2) + (b \times 60) + c + (d \times 60^{-1}) + (e \times 60^{-2})$.

[10]The Gregorian calendar differs from the Julian calendar in that leap years are defined to be years which are divisible by 4, except those that are divisible by 100 unless they are also divisible by 400. In the Julian calendar, every year divisible by 4 is a leap year. Thus, in a 400 year period, there are 3 more leap years in the Julian calendar than in the Gregorian calendar. The Gregorian calendar therefore more accurately approximates the solar year.

[11]Mathematically, a year -n = n + 1 BC.

Part II

The Western Heritage

Chapter 2

Mesopotamia (c. 750 BC – AD 75)

The house of the Chief Scribe is paltry, not even a donkey would enter it.

— Anonymous Assyrian scholar, c. 700 BC; CT 53 14:9f, translated by S. Parpola, *The Forlorn Scholar*, 1987

2.1 Introduction

Up until the end of the last century the little that was known of Mesopotamian astronomy came from scattered references to the "Chaldaeans," portrayed as mystical astrologers in the works of Greek authors such as Strabo and Diodorus Siculus and in the Old Testament, and from the small number of observations contained in Ptolemy's *Almagest* which he attributed to the Babylonians. However, after the archaeological exploration of Assyria and Babylonia by Austin Henry Layard and others which began in the 1840's (Larsen 1996), original cuneiform records have come to light that have transformed this image.[1] It is clear that not only were celestial events used for divination in Mesopotamia (Oppenheim 1969), they were also systematically observed and recorded in Babylon from around the middle of the eighth century BC,[2] whilst by the fourth century BC mathematical schemes had been developed that allowed various astronomical phenomena such as the first rising or last setting of the planets and the time-intervals between successive oppositions and conjunctions of the Sun and Moon to be calculated.[3] Babylonian astronomy was to have a profound and long lasting influence on Greek, Indian, Islamic, and even Medieval European astronomy (Toomer 1988; Pingree 1973; Neugebauer 1963).

Mesopotamia, the land between the rivers, refers to the area of south-west Asia near the Tigris and Euphrates rivers. During the last four millenia BC it was one of the most important powers in the ancient world. By the third millennium BC, a number of city states had come to power, most importantly Sumeria in the south, Babylonia in the thin strip of land between the two rivers just to the south of present day Baghdad, and Assyria, based in the north of the region. In the nineteenth century BC the Amorite dynasty succeeded in unifying the whole of Mesopotamia under Babylonian rule (Oates 1986). This was to be the zenith of Babylonian power in the region, for in the sixteenth century BC Babylon was sacked. There then followed a period of rule by the Kassites, who had come from the mountains to the east of the region. During this period, Assyria began to grow, and by the beginning of the first millennium BC, the Assyrian Empire was the most important power in the

[1] For a history of the recovery of the cuneiform astronomical tablets, see Neugebauer (1957), Baigent (1994) and Stephenson (1997b).

[2] There is no firm evidence for similar systematic observational programmes in the other Mesopotamian cities. However, during the eighth and seventh centuries BC, reports of astronomical observations and their astrological interpretations were regularly sent to the Assyrian kings in Nineveh (Parpola 1970; Hunger 1992).

[3] Aaboe (1974) has described this final type of astronomy as "scientific," that is "a mathematical description of celestial phenomena capable of yielding numerical predictions that can be tested against observations."

Year	Division
c. 750–626 BC	Assyrian Domination
626–539 BC	Chaldaean Dynasty
539–331 BC	Achaemenid Rule
330–311 BC	Macedonian Rule
311–125 BC	Seleucid Period
125BC–	Partian Period

Table 2.1: Important periods in Late Babylonian history (adapted from Oates (1986)).

region. Nevertheless, the city of Babylon continued to have its own ruler, and existed in a state of semi-independence from its Assyrian overlords.

By the beginning of the Late Babylonian period (c. 750 BC), Assyrian domination began to wane, and in 626 BC, Nabopolassar seized the Babylonian throne. In 612 BC the Assyrian capital Nineveh was sacked, a blow from which the Assyrian Empire was never to recover. Nabopolassar's Chaldaean dynasty lasted until 539 BC. In that year the Persian Cyrus marched on Babylon, only to be welcomed into the city as a liberator of the people from the unpopular king, Nabonidus. The Persian Achaemenid dynasty lasted until Alexander the Great defeated Darius in 331 BC. He too was to receive a warm welcome from the Babylonian people. When Seleucus gained control of Babylonia, he made a decision to build a new city, Seleucia, about 60 miles to the north of Babylon. The beginning of Seleucus' reign also marked the beginning of a new era in near-eastern chronology, for from 312 BC onwards, years would be numbered from the Seleucid era, rather than from the reign of each king. Seleucus' successor Antiochus I made the decision to make Seleucia the royal city and began the forced movement of the civilian population of Babylon to this new city (Oates 1986). This was a decision from which Babylon was never to recover, for by the end of the first century AD, the city was deserted. By 125 BC, the Greeks had been driven out of Mesopotamia by the Arsacid Parthians; however, this did not halt the decline of the city of Babylon. For reference, the main divisions of the Late Babylonian period are listed in Table 2.1

The primary motivation for the development of astronomy in Babylon, and more generally throughout Mesopotamia, was astrological. For, according to a Babylonian Diviner's manual:

> "The signs on earth just as those in the sky give us signals. Sky and earth both produce portents; though appearing separately, they are not separate (because) sky and earth are related. A sign that portends evil in the sky is (also) evil on earth, one that portends evil on earth is evil in the sky."
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> [K.2847 Obv. 48–42; trans. Oppenheim (1974)]

Indeed, such was the importance of the the diviner's work that in line 71 of the same text he is warned that he must "pay attention and be not careless!" Astrological interpretations were largely drawn from the great omen series *Enūma Anu Enlil*, which reached its canonical form sometime towards the end of the second millennium BC.

I shall begin this chapter by giving an overview of the various sources of astronomical records in Mesopotamian history. This will mainly concentrate on the Late Babylonian period (c. 750 BC – AD 75), and will include a discussion of the classification and structure of the texts, and comments on the techniques used in their dating. I will then proceed to discuss the timed observations and predictions of both solar and lunar eclipses made by the Babylonian astronomers. Finally, I will discuss the possible methods used in the prediction of eclipses by the Babylonians. Much of what follows is based upon my articles, Steele & Stephenson (1997), Steele (1997), Steele, Stephenson, & Morrison (1997), Steele (1998a), and Steele (1998b).

2.2 Sources of Astronomical Records in Mesopotamian History

Writing in Mesopotamia developed in Sumeria at some time before the end of the fourth millennium BC. Using either a reed or a wooden stylus, pictographs were impressed into a damp piece of clay which, when allowed to dry, retained the image indefinitely, unless the tablet suffered damage. Because of this enduring quality, the tablets provide one of the few sources of "original" texts[4] preserved from the ancient world. The pictographs used by the early Sumerians developed into a form of wedge-shaped writing known as cuneiform. Initially, each cuneiform sign was a logogram indicating a particular word, but later a single sign came to act not only as a logogram, but also had one or more syllabic readings. Because of this, the cuneiform script was very versatile, and it was possible to use it to write not only in Sumerian, but also in the Akkadian language. By the Late Babylonian period, Akkadian had become the dominant language; however, both Sumerian and Akkadian continued to be used in the astronomical texts.

The earliest evidence of astronomical activity in Mesopotamia is found in the great omen series *Enūma Anu Enlil*. This series comprises omens for both astronomical and meterological events such as lunar and solar eclipses, the appearances of planets, and thunder and lightning.[5] It is believed that, whilst the Babylonians had long studied and used the omens, it was not until towards the end of the second millennium BC that the series was compiled in its final form by the Assyrians (Baigent 1994). Individual astrological schools then became established at the major Mesopotamian cities, each of which adopted their own ordering of the series.

Tablet 63 of the *Enūma Anu Enlil* series, often referred to as the "Venus Tablet of Ammiṣaduqa", contains the most ancient series of astronomical observations known from any part of the world. It lists the dates of consecutive first and last appearances of Venus in the evening and morning for the 21 years during the reign of King Ammiṣaduqa of the Babylonian First Dynasty (Sachs 1974; Reiner & Pingree 1975). These observations date from some time during the first half of the second millennium BC; however, despite various attempts to determine their date, for example by Langdon & Fotheringham (1928), Weir (1972) and Huber et al. (1982), there is still no consensus on the chronology of this early period. It has also been argued by Huber et al. (1982) that the omens relating to lunar eclipses must have been based upon earlier observed events. However, these authors have only achieved limited success in attempting to date these events.

Whilst a number of other works from this early period contain astronomical passages,[6] the only other text originally written before the eighth century that is primarily concerned with astronomy is the compendium MUL.APIN. This contains a collection of astronomical knowledge such as a star catalogue, a description of the path of the Moon, and details of the time intervals between the dates of heliacal risings (Hunger & Pingree 1989).

In contrast to the small number of astronomical works written before the middle of the eighth century BC, from this period until the first century AD a vast number of astronomical tablets have been preserved.[7] These may conveniently be split into two groups: letters and reports sent by the astrological scholars to the Assyrian kings of the eighth and seventh century BC which have been found in Nineveh; and a large number of records of astronomical observations and predictions and texts of mathematical astronomy dating from the eighth century BC to the first century AD uncovered

[4]Or, at least, near-original texts as a number were obviously copied in antiquity by the Babylonian scribes. However, they are still only, say, second or third generation copies. By contrast, the writings from ancient China of this period were written on perishable materials, and so we only possess late copies of the works that have gone through the copying process, with all of its inherent problems of corruption to the text, many times.

[5]For a survey of the *Enūma Anu Enlil* series, see Weidner (1944). The tablets concerned with lunar eclipses have been edited by Rochberg-Halton (1987, 1988), and parts of those dealing with the planetary omens by Reiner & Pingree (1975, 1981).

[6]For example, the "Epic of Creation", *Enūma eliš*, outlines, albeit rather obliquely, the Mesopotamian cosmology (Britton & Walker 1996; Lambert 1975).

[7]It should be noted that although works such as *Enūma Anu Enlil* and MUL.APIN were written well before this time, they are only preserved in copies made during this later period.

in Babylon. A small number of astronomical texts have also been found in other cities, most notably a number on mathematical astronomy in Uruk. However, these reflect the Babylonian astronomical methods and so will be considered along with them. About 95% of the astronomical tablets are now held by the British Museum in London.

The Assyrian texts almost all date from the reigns of the Kings Esarhaddon (681–669 BC) and Assurbanipal (669–648 BC). They may be divided into two classes: letters and reports. The letters, which have been published by Parpola (1970),[8] were written by scholars on various matters, usually in response to a question from the king. Many of the letters concern celestial observations and divination, for example:

> "To the king, my lord, (from) your servant Nabû-aḫḫē-erība: Good health to the king, my lord! May the gods Nabû (and) Marduk bless the king, my lord. As regards what the king, my lord, wrote to me: 'Is it favourable for the crown prince to enter into the presence of the king?', it is very favourable. The crown prince may enter into the presence of the king, my lord, this (very) day. May the gods Bēl (and) Nabû lengthen his days, (and) may the king, my lord, see him prosper! The month is good, this day is good: the planet Mercury is the crown prince, (and) it is vis[ib]le in the constellation [Ari]es; the planet Venus [is] visible in [Bab]ylon, in the home of his dynasty; the Moon god will supply the day in the month Nisannu. We count this together: it is fortunate."
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> [LAS 70; trans. Parpola (1970: 47)]

The second group of Assyrian texts are the astrological reports of the specialists in divination employed by the king to report both their celestial observations, and to give an interpretation. Unlike letters, reports were generally sent unsolicited on the basis of the observations made by the diviners. The reports, which have been published by Hunger (1992),[9] often simply contain a quotation from the omen series *Enūma Anu Enlil*. This is sufficient for it to be inferred that the observation was made, for the protasis of an observation always implies an observation (Hunger 1992). However, in a number of cases, the observation is described, and sometimes explanatory remarks about the omen are also given. For example:

> "[If] on the 14th day the Moon and Sun [are seen together]: reliable speech; the land will become happy; [the gods] will remember [Akkad] favorably; joy [among the troops]; the king will reach the highest rank; the cattle of [Akkad wi]ll lie in the steppe undisturbed. If the Moon and Sun are in opposition: the king of the land will widen his understanding. I.e., on the 14th day each [month one god] will [be seen with the other]. (The Moon) came into opposition with [the Sun] on the appropriate day, and [its] position is equal (to the Sun's) portending a reign of long days, (and) well-being of the king of the world and [his] people. [From] Rašil the elder, servant of the king."
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> [ARAK 395; trans. Hunger (1992: 226)]

The large number of astronomical tablets recovered from Babylon reflect a much greater diversity of date and content than the Assyrian texts. Unfortunately there is no archaeological record for the discovery of these texts; most were in fact bought by the British Museum from Baghdad antique dealers, and even those that were recovered from excavations made on behalf of the Museum by H. Rassam at around the turn of the present century were not systematically recorded. Nevertheless, it is clear from other evidence — the fact that other tablets contained in the same museum collections have their provenance expressly mentioned, the character of the personal names which appear in the colophons, and the particular deities mentioned in the introductory invocations (Sachs 1948) — that they all originated from either Babylon or the neighbouring city of Borsippa. Furthermore, there is

[8] In the following discussions, the letters are denoted by their LAS number in Parpola (1970). For a table of concordances with museum numbers, see Parpola (1970: 325–329).

[9] In the following discussions, the reports are denoted by their ARAK number in Hunger (1992). For a table of concordances with museum numbers, see Hunger (1992: 374–379).

no difference in style between the fifty or so astronomical texts excavated by Rassam at Babylon, and those of uncertain provenance.

The first attempt to classify the Babylonian astronomical tablets was by Sachs (1948). Working from only a handful of examples he classified the tablets into "Astronomical Tables", later to become known as ACT texts after their publication under the title *Astronomical Cuneiform Texts* by Neugebauer (1955), "Almanacs", "Normal Star (NS) Almanacs", "Goal-Year Texts", and "Astronomical Diaries". In *Late Babylonian Astronomical and Related Texts* (LBAT) Sachs (1955) expanded his survey to include over 1500 tablets, and published copies of many of them drawn by T. G. Pinches and J. N. Strassmaier.[10] Sachs' earlier classification remained valid for most of the new material, with the addition of a new class of texts which he described as "Planetary and Lunar Observations". It is possible to group the various categories of astronomical texts into two main divisions: the ACT texts of mathematical astronomy, and those texts that contain actual observations and predictions made by the Babylonian astronomers, known, for want of a better name, as Non-Mathematical Astronomical Texts (NMAT). Unsurprisingly, the ACT texts developed much later than the NMAT texts; the earliest ACT texts come from the beginning of the Seleucid era (c. 300 BC), whereas the NMAT texts contain records dating from as early as the eighth century BC.

Before I proceed to discuss the various types of Late Babylonian Astronomical Text in detail, it is necessary to consider when systematic astronomical records began to be kept in Babylon. In his *Almagest* (III, 3), the second century Greek astronomer Ptolemy stated that he had access to Babylonian astronomical records from the beginning of the reign of Nabonassar.[11] There is also an Hellenistic tradition that:

> "From the time of Nabonassar, the Chaldaeans accurately recorded the times of the motions of the stars. The polymaths among the Greeks learned from the Chaldaeans that — as Alexander (Polyhistor) and Berossus, men versed in Chaldaean antiquities, say — Nabonassar gathered together (the accounts of) the deeds of the kings before him and did away with them so that the reckoning of the Chaldaean kings would begin with him."
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> [(Pseudo-)Berossus of Cos; trans. Brinkman (1968: 227)]

Whilst the suggestion that Nabonassar deliberately destroyed all earlier records is probably no more than an attempt by later historians to explain the fact that the ages before his time were so poorly documented (Brinkman 1968), the statement that Nabonassar initiated the Babylonian tradition of systematic astronomical records appears to be borne out by other evidence (Hallo 1988). The Babylonian Chronicle Series, which details important historical events, in particular those involving the king, begins with Nabonassar. The Astronomical Diaries, the earliest of which has been dated to 652 BC, also contain, at the end of the astronomical observations for each month, a brief account of the important historical events that have occurred. Grayson (1975) has suggested that these entries in the Astronomical Diaries may have been the source for the chronicles, or at the very least, that the chronicles and the Diaries had a common source. Furthermore, the tablet LBAT *1414, which lists successive lunar eclipse observations and predictions, contains a record that has been firmly dated to the 9th April 731 BC, just after the end of Nabonassar's reign. Another tablet, LBAT 1413, also contains successive lunar eclipses, and was tentatively dated by Sachs (1955) to 747 BC, Nabonassar's ascension year. However, as Huber (1973) has noted, there are problems with establishing the date of this tablet, and so I shall postpone further discussion of it until Section 2.3 below.

As I have mentioned above, the Late Babylonian Astronomical Texts may be divided into a number of categories within two main groups: the ACT texts of mathematical astronomy, and the NMAT texts of non-mathematical astronomy. As this study will primarily be concerned with the NMAT

[10] In the following discussions, I will denote texts published in Neugebauer (1955) by their ACT number, and texts listed in Sachs (1955) by their LBAT number (* and ** LBAT numbers refer to tablets listed in Sachs (1955), but for which a copy was not included.) Texts not published in either of these sources will be denoted by their museum numbers. For lists of concordances between ACT, LBAT and museum numbers, see Neugebauer (1955: 453–459) and Sachs (1955: xi–lvi).

[11] See, for example, the translation of Toomer (1984: 116).

texts, I will begin by discussing these texts first. The following descriptions are largely based upon those given by Sachs (1948), Sachs (1974), Sachs & Hunger (1988), and Hunger (1998).

The fundamental observational text of the Babylonian astronomers was the Astronomical Diary. As discussed above, it is believed that these began to be kept from the time of the reign of Nabonassar. However, as noted above, the earliest extant Diary has been dated to 652 BC, and there is only one more example (568 BC) preserved from before the fifth century BC. Survivals occur with gradually increasing frequency during the next three centuries, until in the second century BC, examples from about three-quarters of each year are preserved. During the fist century BC the frequency of survivals drops off again, and no Diaries are extant which are dated later than 59 BC.[12] In many of these cases, however, the preserved Diaries are only fragments of the original texts, and contain information for only part of the period which they originally covered. Furthermore, less than half of the known Diary fragments have been dated, although the others are generally too small to be of great interest in any case. All of the datable Diaries have been published in translation and transliteration by Sachs & Hunger (1988, 1989, 1996).

Typically, an Astronomical Diary contains a day by day account of the observations made by the Babylonian astronomers, for a period of six or seven months. Each month begins with a statement about the number of days in the previous month, and then a measurement of the time between sunset and moonset on the evening of that first day. The time interval between the Moon and the Sun crossing the horizon is also recorded a further five times during the month, four at full Moon, and the final measurement at the end of the month. These intervals, which Sachs (1948) dubbed the "Lunar Six", are listed below:[13]

na	The time between sunset and moonset when the Moon was visible for the first time after conjunction
ŠÚ	The time between moonset and sunrise when the Moon set for the last time before sunrise
na	The time between sunrise and moonset when the Moon set for the first time after sunrise
ME	The time between moonrise and sunset when the Moon rose for the last time after sunset
GE_6	The time between sunset and moonrise when the Moon rose for the first time after sunset
KUR	The time between moonrise and sunrise when the Moon was visible for the last time before conjunction

Throughout the month, other lunar observations, such as the passing by of the 31 "Normal Stars"[14] and eclipses of the Sun or Moon, are also recorded in the Diaries. Planetary phases, planetary positions relative to the Normal Stars, solstices and equinoxes, Sirius phenomena, and occasionally events such as comets, meteors and bad weather, are also reported in the Diaries. Finally, at the end of every month, a brief summary of the level of the river Euphrates, the value of six essential commodities, and any important events in the life of the city, would be reported (Sachs & Hunger 1988).

Whilst most of the contents of the Diaries represent observations, it is important to note that the Diaries do also contain a number of predictions. Generally, these predictions are in place of events which were watched for, but, often on account of bad weather, could not be seen. For example, a number of lunar six measurements are followed by the words NU PAP, meaning "not seen" and

[12] The distribution of years with at least one dated Diary fragment is shown graphically in Figure 2 of Sachs (1974). Although a small number of additional Diary fragments have subsequently been dated, these would not significantly alter this figure.

[13] These definitions are based upon those of Sachs & Hunger (1988: 20).

[14] The Normal Stars were a group of bright stars located close to the ecliptic that were used as reference points in the sky. For a list of the Babylonian Normal Stars, see Sachs & Hunger (1988: 17–19).

indicating that the time was calculated, whereas some others end with *muš*, "measured". Similarly, a number of eclipses are predicted that could not be seen because the luminary was below the horizon at the time of the eclipse (i.e., a lunar eclipse during the hours of daylight, or a solar eclipse during the night).

From the Astronomical Diaries, the Babylonians abstracted records to compile texts that have become known as "Goal-Year Texts" (Sachs 1948). These texts contain information that was to be used in making predictions for a specific "Goal" year. This information comprises lunar and planetary observations, or a prediction if no observation was made, taken from a number of years ago corresponding to one cycle in the well known periods of the Moon and planets (e.g., 18 years for the Moon, 8 years for Venus, etc.). Although Hunger (1998) has noted that there are a small number of cases where the observations recorded in the Goal-Year texts do not correspond exactly with the descriptions given in the Diaries, he has plausibly suggested that these Goal-Year texts drew on other Diaries than the ones that happen to be preserved, as there are cases where parallel Diaries give slightly different accounts of the same event. The earliest extant Goal-Year Text contains entries for a Goal-Year of the 76th year of the Seleucid Era, which is equivalent to 236 BC, whilst the latest is for the 288th year of the Seleucid Era, or 24 BC. Although copies of many of the Goal-Year Texts were included in Sachs (1955), only a few of these tablets have as yet been published in transliteration or translation.

Around the same period, the Astronomical Diaries were also used to compile lists of individual planetary and lunar phenomena. Most important among these lists are those containing successive eclipse observations and predictions. As I have mentioned, the earliest reliably dated list contains eclipse records stretching back to 731 BC. The latest continues down to 160 BC. Complementary to these lists are a number of tablets which are dedicated to describing an individual eclipse. These range in date from 284 BC to 10 BC. Transliterations and translations of these texts are currently being published by Sachs & Hunger (1998)

The final two categories of NMAT are the Almanacs and the Normal Star Almanacs. Neither of these types of text contain any observations. Instead, they detail predictions of many of the elements of an astronomical diary for a forthcoming year. Until recently, it had generally been assumed that these predictions were made using the information collected in the Goal-Year texts, and that they in turn provided the source of the predictions in the Diaries. Thus, there was taken to be a closed circle in which records were abstracted from the Diaries into the Goal-Year Texts, which in turn were used to produce the Almanacs and Normal Star Almanacs, which would finally be fed back into the Diaries as the predictions of unobserved events. However, Hunger (1998) has shown that it may not have been as simple as this. If the Almanacs and Normal Star Almanacs were produced from the Goal-Year texts, then the values in the Goal-Year texts were not simply put into the Almanacs and Normal Star Almanacs, but were modified in some fashion. What this modification was and how it was applied are not yet clear, but it is possible that it involved using the ACT type texts, which otherwise appear to have been of no practical use. Dated Normal Star Almanacs range from the 31st year of the Seleucid Era to the 212nd year (281–100 BC), whereas the Almanacs range from 92nd year of the Seleucid Era (220 BC) to as late as the 385th year (AD 75). Once again, whilst copies of many of the Almanacs and the Normal Star Almanacs were included in Sachs (1955), very few have been published in transliteration or translation.

Let me now move on to the ACT type texts, most of which have been published by Neugebauer (1955). These may be split into three classes called by Neugebauer "Ephemerides", "Auxiliary Functions", and "Procedure Texts". The Ephemerides list, for example, the position of the Sun, the Moon, or a planet for a regular time interval such as a day or a month. The texts were not just used to track the motions of these bodies, however, but rather to predict phenomena such as first and last visibilities, the lunar six, and eclipses (Neugebauer 1955). In order to construct the Ephemerides, texts of Auxiliary Functions, such as the velocity of the Sun or Moon, were written. Finally, the Procedure Texts outline the rules for computing the Ephemerides. The ACT texts range in date from shortly after the beginning of the Seleucid Era, to the middle of the first century AD.

The relationship between the ACT and the NMAT texts is at present far from clear. Naïvely, we might assume that the observations contained in the Diaries would provide the raw data from which the ACT schemes were developed, and indeed Aaboe (1980) and Swerdlow (1998) in the field of the ACT planetary theories, and Brack-Bernsen (1990) and Brack-Bernsen & Schmidt (1994) for elements of the lunar theory, have proposed methods by which this may have been done; however, these are only partial solutions to this problem and much more work remains to be done.

Finally, let me pose the question, "Who were the Babylonian astronomers, and from where did they observe?" The earliest evidence in answer to this question is found in the description of the Babylonian Ziggurat, the famed "Tower of Babel", by Diodorus Siculus:

> "... in the centre of the city (is) a temple of Zeus whom, as we have said, the Babylonians call Belus. Now since with regard to this temple the historians are at variance, and since time has caused the structure to fall into ruins, it is impossible to give the exact facts concerning it. But all agree that it was exceedingly high, and that in it the Chaldaeans made their observations of the stars, whose risings and settings could be accurately observed by reason of the height of the structure."
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> [*Bibliotheca Historica*, II, 9; trans. Oldfather (1933: 381)]

The reliability of this account must, however, be questioned. According to Arrian, the Ziggurat was destroyed by Xerxes in the fifth century BC (*Anabasis*, VII, 16), and although Alexander made plans to have it rebuilt in the fourth century BC, these were never completed. It seems more likely that, at least in the early period, the astronomers observed from either a building within the city (perhaps the temple), or from the city walls. In the ancient world, these walls were considered to be among the great technological achievements of the Orient. Their fame can probably be attributed to the account of Babylon given by Herodotus:

> "(Babylon) is surrounded by a broad deep moat full of water, and within the moat there is a wall fifty cubits wide and two hundred high ... On top of the wall they constructed, along each edge, a row of one-roomed buildings facing inwards with enough space between for a four-horse chariot to pass. There are a hundred gates in the circuits of the wall, all of bronze with bronze uprights and lintels."
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> [*Historia*, I, 181; trans. de Sélincourt (1979: 113)]

Plainly, Herodotus' account cannot be considered to be the literal truth; a height of 200 cubits, or about 100 meters, for the wall is inconceivable. Archaeological evidence, discussed by Ravn (1942), suggests a height of between 10 and 20 meters.

The identity of the observers at this early period is also unclear. In the Greek and Latin classics, the word "Chaldaean" is often used as a synonym for astrologers and diviners (de Kuyper 1993). The writings of Herodotus makes it clear that the Chaldaeans are to be identified with the priests of Bel. This suggests that the early Babylonian astronomers were linked to the temples, a suggestion which will reappear again for the astronomers of the Seleucid period. One other possibility is that the astronomers were employed by the king. This certainly happened in the Assyrian capital of Nineveh, where the king employed a number of scholars to make celestial observations and to interpret the omens for him (Oppenheim 1969).

By the Seleucid period, the situation had changed. Babylon was no longer a royal city, and so there can be no suggestion that scholars were employed by the king to make observations and divinations. The development of mathematical astronomy in the ACT texts also leads us to the question "Were the ACT texts compiled by the same group of astronomers as made the observations recorded in the Diaries, or were there two independent groups of astronomers?" Neugebauer (1989) was firmly of the latter opinion, remarking that "nothing compels us to assume that these two groups of professional men considered one another with particularly kind feelings." However, Rochberg (1993) has convincingly argued that a group of scholars called *ṭupšar Enūma Anu Enlil* "Scribes of *Enūma*

Anu Enlil', who were responsible for making the observations that were recorded in the Diaries and producing the Almanacs for a forthcoming year, were also the authors of some of the ACT type texts. She further argues that these scribes were based in the Babylonian temples, namely the Esagila in Babylon and the Bit Reš sanctuary in Uruk.

Further evidence that, at least in the Hellenistic period, the astronomers were associated with the Esagila is found in two temple documents:

> "Bel-lumur, the dean of Esagila and the Babylonians of the assembly of Esagila took council together on 24 Ajar and said, 'Itti-Marduk-balaṭu, the building inspector (?), who is in charge of the city, the commissar of temples, the astrologer, son of Iddin-Bel, whom we sent (?) earlier to king Hyspaosines, (and) who drew supplies at the royal gate — now it has come to pass that his sons, Bel-aḫḫe-iddin and Nabu-mušetiq-uddi are now capable of making observations and are (now) equal with the aforementioned Bel-lumur and the Babylonians of the assembly of Esagila. We shall give Bel-aḫḫe-iddin and Nabu-mušetiq-uddi from this day forward two mina of silver, the ration of Itti-Marduk-balaṭu, his son, their father out of our supplies in accordance with whatever their father, Itti-Marduk-balaṭu has drawn. They will make the observations and give the yearly calculations together with Bel-naṣiršu, the astrologers and assistant astrologers.'"
>
> [BOR 4, 132; trans. McEwan (1981: 18)]
>
> "... (the dean of Esagila and) the Babylonians of the assembly of Esagila took council together and said, 'On 15 Ṭebet, year 129 (Arsasid Era), which is year 193 (Seleucid Era), we drew up a memorandum concerning our common holdings (to the effect that) one mina of silver, the currency of Babylon, and the arable land of Bel-aba-uṣur, the astrologer, son of Bel-rimanni, which he enjoyed (?) for carrying out the observations (and in which) we installed Nabu-apla-usur, the lamentation priest and astrologer. Now Bel-naṣiršu the astrologer, son of Bel-aba-uṣur mentioned above, has gone through everything and we have instructed him. He is capable of carrying out the observations. We have seen (?) that he is capable of making the observations and we have approached the aforementioned Nabu-apla-uṣur, who had had free use of the arable land and one mina of silver, the ration of which Bel-aba-uṣeu, the father (of Bel-naṣiršu) for two years. And he has made it free for Bel-naṣiršu, who is thereby (?) equal with us (?), so that we shall give him yearly, from this year on, the aforementioned one mina of silver in the currency of Babylon and the arable land from the account for our needs. He will make the observations and give the calculations and measurements together with Labaši, Muranu, Marduk-šapik-zeri, son of Bel-uballissu, Bel-aḫḫe-uṣur, Nabu-mušetiq-uddi, son of Itti-Marduk-balaṭu and with the assistant astrologers.'"
>
> [CT 49, 144; trans. McEwan (1981: 19–20)]

These two documents suggest that the Scribes of *Enūma Anu Enlil*, which McEwan (1981) translates rather ambiguously as "astrologers", were members of their own guild within the temple, and that membership of this guild was, at least partly, decided on a hereditary basis. For further support of Rochberg's (1993) conclusion that the astronomers were based in the Esagila temple, I may mention the accounts of Strabo and Pliny. Strabo visited the city in 24 BC and wrote that it was:

> "... in great part deserted, so that no-one would hesitate to apply to it what one of the comic writers said of Megalopolitae in Arcadia, 'The great city is a great desert'."
>
> [*Geographica*, XVI, 1, 5; trans. Hamilton & Falconer (1906: 145)]

Shortly after Pliny wrote:

> "The temple of Jupiter Belus in Babylon is still standing — Belus was the discoverer of the science of astronomy; but in all other respects the place has gone back to a desert."
>
> [*Historia Naturalis*, VI, 30, 121; trans. Rackham (1942: 431)]

The "temple of Jupiter Belus" referred to by Pliny is the Esagila. From these two accounts it would therefore appear that the Esagila was one of the few buildings still inhabited in the latter half of the first century BC. The fact that we have an account of an observation of a solar eclipse in 10 BC[15] indicates that the astronomers were still active in the city at that time. This provides further support in favour of the argument that the Esagila temple was the centre of this astronomical activity. Furthermore, the fact that Almanacs have been found from as late as AD 75, suggests that the astronomers were still active as late at the latter half of the first century AD. By AD 116, however, Trajan found that the city was finally deserted after thousands of years as one of the great centres of civilization in the world (Oates 1986).

2.3 Dating Babylonian Astronomical Tablets

As I have mentioned above, the majority of the cuneiform tablets containing astronomical records are now held by the British Museum. They were all recovered, either directly by excavations sponsored by the Museum, or indirectly from antique dealers in Baghdad, from the site of Babylon during the nineteenth century. Sadly, many of these tablets were badly damaged when first dug up, and despite many successful restorations by joining fragments of the same tablet together, a large number of texts still remain in a woeful condition. In many cases, the line of writing containing the date of the record, which is usually one of the first lines on the tablet, is either broken away, or is only partially preserved. Sometimes it is possible to date the tablet on account of the historical remarks contained within it, but this is the exception rather than the norm. Fortunately, however, because of the nature of the astronomical texts — in that they contain observations of the heavens — it is often possible, at least if the tablet is reasonably large, to date it using astronomical means. The basic principal of this technique is to calculate, using modern theories of celestial motion, the positions of the heavenly bodies at times in the past to try to obtain a unique date at which the observations contained in the text could have been made. In his classification of the LBAT, Sachs (1955) derived dates in this fashion for a number of tablets. As a result he was able to publish dates, which were either preserved on the tablet or that he had derived, for about half of his catalogue.

Before I describe the procedure of dating a Babylonian astronomical text by astronomical methods, it is necessary to give some details on the Babylonian calendar. Essentially, the Babylonians, in common with many ancient civilizations, used a luni-solar calendar, that is a month length based upon the motion of the Moon, and a year length based upon the motion of the Sun. A Babylonian month was defined as beginning on the evening when the lunar crescent becomes visible for the first time. Each month thus contained either 29 or 30 days, a day lasting from one sunset to the next. If the lunar crescent was still not visible after 30 days, say because of cloud cover, then the month was begun anyway; thus there are no months lasting 31 days in the Babylonian calendar. The names of the 12 Babylonian months are given in Table 2.2. In the astronomical texts the months are usually given by their abbreviated names, rather than in their full form. It has become customary in translations to render the months names as a roman numeral (i.e., Nisannu or BAR is usually given as "Month I".)

Because the length of a solar year is about 11 days longer than that of 12 lunar months, the Babylonians inserted extra "intercalary" months about every three years. Initially these could be inserted at any time of the year, but by the Late Babylonian period, they were only placed after the sixth and the twelfth months. These intercalary months are denoted in translations as "Month VI_2" and "Month XII_2". Before the sixth century BC there is no evidence for use of any scheme to calculate when to insert an intercalary month, despite the fact that possible schemes are attested in MUL.APIN; instead, they were simply added whenever it was considered necessary. Starting around 527 BC, however, Britton (1993) has found evidence that an 8-year intercalation cycle was used, to be replaced in 503 BC by a 19-year cycle. Although there are occasional exceptions when this scheme was not used consistently,[16] it seems to have been used continually from the fifth century BC, down

[15]See Section 2.3.1 below.

[16]For details, see Figure 2 of Britton (1993)

Month	Name	Abbreviated Name
I	Nisannu	BAR
II	Ajjaru	GU_4
III	Simānu	SIG
IV	Du'ūzu	ŠU
V	Abu	IZI
VI	Ulūlu	KIN
VII	Tešrītu	DU_6
VIII	Araḫsamnu	APIN
IX	Kislīmu	GAN
X	Ṭebētu	AB
XI	Šabāṭu	ZÍZ
XII	Addaru	ŠE

Table 2.2: Babylonian month names (after Sachs & Hunger (1988: 13–14)).

through the Seleucid Era.

From an early time, regnal years were used in the Babylonian calendar. Regnal years are a count of the number of years that have past since the accession of each king. For example, the 21st year of Nabonassar, his final, lasted from April 605 BC to March 604 BC in the Julian calendar. It was followed by the 1st year of his successor, Nebuchadnezzar II. The practice of using regnal years continued until the reign of Seleucus I, after which date years were generally given in terms of the number of years from his accession. This was known as the Seleucid Era. After the middle of the third century BC, dates are often given both in the Seleucid Era, and in the Arsacid Era, which originated in Iran in 247 BC.

In converting from the Babylonian calendar to the Julian calendar, it is necessary to know not only the length of each reign period, but also the length of each month, and when months were intercalated. Parker & Dubberstein (1956) have made an extensive investigation of these problems, and their tables allow dates from the beginning of Nabopolassar's reign (626 BC) to the 386th year of the Seleucid Era (AD 75) to be converted to the Julian calendar with ease.

Let me return now to the method of dating a Babylonian astronomical tablet if the date is either wholly or partially destroyed. The basic principle in this procedure is to compare any preserved observations with the results of retrospective computations. Observations that may be of use in this context include solar and lunar eclipses, planetary visibilities and positions, stellar visibilities, lunar positions, and any measurements of the lunar six. Before commencing this process, however, it is necessary to establish a range of possible dates for the tablet. From the arguments presented in Section 2.2 above, it is safe to assume that the Babylonian texts are unlikely to come from before 750 BC or after AD 100. For some tablets, it may be possible to further restrict this date range on linguistic or historical grounds. Modern theories of the motion of the Sun, Moon, and planets are then used to accurately determine their positions over dates in this period. To illustrate this process, I give below four examples of the tablets dated using this method.[17]

2.3.1 LBAT 1456

LBAT 1456 is a small tablet containing a record of an observation of a solar eclipse. Sadly the tablet is badly damaged and both the date and a number of details of the eclipse have been lost. A drawing of the tablet by T. G. Pinches has been published by Sachs (1955). Due to the unusual terminology used in the text, Sachs described it as possibly being astrological rather that observational in nature. However, subsequent readings have resolved this uncertainty.

[17] The tablets have been dated at the request of Prof. H. Hunger for their publication in Sachs & Hunger (1998). In all cases, I have worked from his translations of the texts.

I reproduce below a preliminary translation of the twelve lines of badly damaged text on this tablet kindly supplied by Prof. H. Hunger.

1. [...] ... [...]
2. [...] the 28th, solar eclipse; fr[om ...]
3. [...] it began; 23° of day to the inside of the sun ... [...]
4. its ... were clear(?); 2° [...]
5. Venus, Mercury, eclipse ...; the remainder(?) [...]
6. Sirius, which had set, in its non-[...]
7. In its eclipse, ... [...]
8. people broke pots [...]
9. they broke. In 23° of day it cleared from north [and west]
10. to south and east. 48° onset, [maximal phase,]
11. and clearing. In its eclipse, the north and west wind blew.
12. 1,30° (=90°) of day before sunset. The 28th, moonrise to sunrise: 17° 30', measured.

The text describes a large solar eclipse during which the planets Venus and Mercury and the star Sirius were visible. The eclipse began at 90°, or 6 hours, before sunset, and lasted for 48°, or 3.2 hours.[18] The date of this tablet can be established primarily because of the observation that Venus, Mercury, and Sirius were visible during the solar eclipse. For this to be the case, over 0.95 of the apparent solar diameter would have probably been obscured at the maximum phase of the eclipse. Large solar eclipses are only infrequently visible at any given location on the Earth's surface, and so these details considerably reduce the range of possible dates for the eclipse.

There were only eight solar eclipses with magnitudes greater than 0.95 visible in Babylon between 750 BC and AD 100. Their dates are 19 May 557 BC, 18 January 402 BC, 15 June 242 BC, 10 October 174 BC, 15 April 136 BC, 30 June 10 BC, 24 November 29 AD, and 30 April 59 AD. Tablets containing observations of the eclipses on two of these dates, 15 June 242 BC, and 15 April 136 BC, have already been securely dated. As the description and the timings of the eclipse found on LBAT 1456 radically differs from the reports found on these other tablets, it is possible to immediately discard these two dates as possibilities for this record. The dates 18 January 402 BC, 10 October 173 BC, and 24 November 29 AD may be discarded as Sirius would have been below the horizon at the time of the eclipse. On 19 May 557 BC Mercury would have set during the eclipse and so would probably not have been visible. Also the timings given in the report are very different to those given by modern computations. On 30 April 59 AD Mercury, Venus and Sirius would have been above the horizon but Mercury would be too faint (mag. = +0.5) to be visible as the computed magnitude of this eclipse was only magnitude 0.96. There is also a poor agreement between the recorded and computed time of the eclipse. Thus this date may also be discarded.

The date of 30 June 10 BC is in excellent agreement with the observed details of the eclipse. Mercury, Venus and Sirius were all visible during the eclipse. There is also good agreement between the recorded and computed times. By computation, the eclipse began at a local time 12.80 hours. This corresponds to about 95° before sunset, very close to the 90° quoted in the last line of the tablet. The eclipse is computed to have lasted for about 40°, slightly shorter than the 48° given for the total duration in the tenth line. However, errors of this size in the timing of eclipses are in no way unusual (Steele, Stephenson & Morrison 1997). It is therefore possible to confidently assign this date to the observation on this tablet.

Figure 2.1 shows the position of the observed heavenly bodies at the time of mid-eclipse. By computation, Babylon was just within the path of totality of the eclipse. This may explain the dramatic nature of the language used in the report — the act of smashing pots and making noises in response

[18] The Babylonian unit of time was the UŠ. As there were 360 UŠ in one day, it is customary to render UŠ as "degree" or ° in translations. See Section 2.4 below for further details.

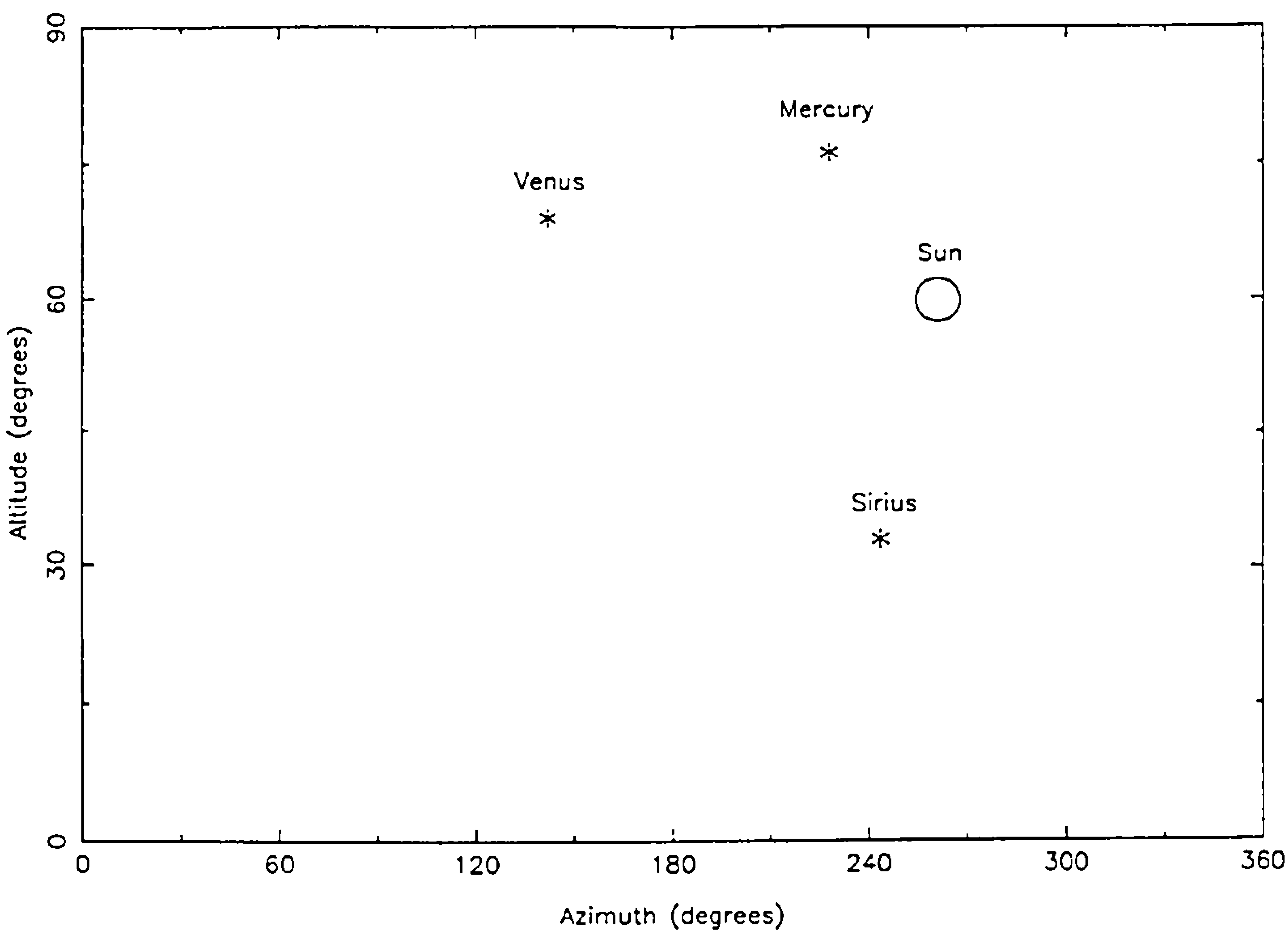


Figure 2.1: The positions of Mercury, Venus and Sirius at the maximum phase of the solar eclipse on 30 June 10 BC.

to an eclipse is known worldwide (Beaulieu & Britton 1994). For example, in a seventh century BC letter to the Assyrian king describing the observation of an eclipse, Mār-Ištar wrote that "a bronze kettle drum was set up."[19] Much more recently, during the total solar eclipse seen in Thailand on 24 September 1995 AD, I am told that people banged on pans to ward off evil.

The report of the eclipse on LBAT 1456 is the latest yet known from Babylon. Furthermore, it may be one of only two total solar eclipses for which we have a record of its observation preserved in Babylonian history.[20] The question of whether the eclipse was total will be addressed in Section 2.5 below.

2.3.2 BM 38357

This tablet has two columns on each of the obverse and reverse. The text contains not only an eclipse observation, but also a number of historical events, such as the death of the governor of Nippur. Column II of the obverse contains an observation of a lunar eclipse in month VI of a year 16. In the column II of the reverse, a year 19 is mentioned, therefore the tablet must date from a king who reigned for at least 19 years. I quote the record of the lunar eclipse on lines 4'–15' of column II of the obverse from Prof. H. Hunger's translation:

4' Year 16, month II, the 20th [...]

[19] LAS 278; trans. Parpola (1970: 225).

[20] It should be noted that at no stage in establishing the date of this tablet has it been assumed that the eclipse was total, which would require the Earth's rotational clock error, ΔT, to be confined to a small range of values. The only assumption that was made was that the eclipse must have a magnitude of greater than 0.95, which is given for any sensible value of ΔT. Thus, if it can be decided that the eclipse was total, it can be used to refine our present knowledge of ΔT at this period. This will be discussed further in Section 8.2 below.

5' went in order to do battle. Month III, [...]
6' captives from the land Ruṣapu [...]
7' Month VI, night of the 14th, 5 [...]
8' 10° of night in the middle (watch) [...]
9' remained, lunar eclipse; more than [...]
10' on the south side was covered [...]
11' beginning of the night, after ... [...]
12' the bright star of [...]
13' to the south, ... [...]
14' 10° night [...]
15' in ... [...]

The date of this eclipse may be established simply from the partially preserved date. Between 750 BC and AD 100, the only reign periods to have lasted for at least 19 years are those of Nabopolassar (626–605 BC), Nebuchadnezzar II (604–562 BC), Darius I (521–486 BC), Xerxes (485–465 BC), Artaxerxes I (464–424 BC), Darius II (423–405 BC), Artaxerxes II (404–359 BC), Artaxerxes III (358–338 BC), and, of course, the Seleucid Era (311 BC onwards). Of these, only in the 16th year of Nabopolassar was there a lunar eclipse visible in Babylon during month VI. Therefore this must be the date of this report. After I had proposed the date for this record, Prof. Hunger noted that the words surrounding the report are parallel to those found in a chronicle reporting events from Nabopolassar's reign, which provided further proof for the date of this tablet.

2.3.3 LBAT 1452

This is a small, badly damaged tablet containing a report of a lunar eclipse. A drawing of the tablet by T. G. Pinches has been published by Sachs (1955). I quote below Prof. H. Hunger's translation of the 10 lines of damaged text:

1' [...] ... [...]
2' [... lunar] eclipse; when it began, in 22° of night all
3' [...] ... was covered. 22° of night maximal phase. When it began to clear,
4' it cleared [in 21° of night from] east to west. 65° onset,
5' [maximal phase, and clearing.]] Its eclipse was red. Lightning on the south side
6' [...] flashed (?).
7' [...] and east wind blew; during clearing, the north wind blew. In its eclipse, ...
8' [... and Sat]urn stood there; in the beginning of onset, Sirius set.
9' [...] α Virginis it was eclipsed ... [...]
10' [...] ... [...]

The text describes a lunar eclipse during which Saturn was visible. Sirius set during the eclipse, which lasted for a total of 65° or 4.33 hours. At the time of the eclipse, the Moon was in the region of the star α Virginis. The individual phases of the eclipse are quoted to the nearest UŠ, which suggest a date after about 560 BC for the eclipse. Before this period, times are generally only quoted to the nearest 5 or 10 UŠ.

The critical observations in establishing the date of this tablet are that the Moon was near α Virginis, that Saturn was visible during the eclipse, and that Sirius set during the course of the eclipse. At an eclipse, the Sun and Moon are in opposition. Therefore, if the Moon has a longitude of about 173°, the Sun must have a longitude of about 356°, and so the eclipse must have taken place during the months of March or April. Between 560 BC and AD 100 there were only 12 lunar eclipses visible in Babylon from their beginning to end in these months. They are 2 April 508 BC, 14 April 425 BC, 6 April 378 BC, 5 April 359 BC, 7 April 294 BC, 17 March 284 BC, 28 March 247 BC, 20 March 135 BC, 1 April 52 BC, 22 March 5 BC, 24 March 61 AD, and 4 April 79 AD. Only during seven of these eclipses was Saturn visible, and so the other dates may be discarded. In all but two of these dates, Sirius was either not visible during the eclipse, or else it was visible during the whole of the eclipse. This only leaves two dates: 17 March 284 BC and 1 April 52 BC. On the former date, the lunar longitude was about 172°, which is within 1° of that of α Virginis. For the latter date, however, the lunar longitude was about 189°, which, while still being in the general region of α Virginis, is much closer to α Libra, and so it would be expected that, in this second case, the Moon would have been said to be near α Libra rather than α Virginis. LBAT 1452 can therefore be dated to 17 March 284 BC.

2.3.4 LBAT 1413

This tablet records observations of four successive lunar eclipses observed in the accession, 1st and 2nd years of an unknown reign. This is followed by two predictions for the 2nd and 3rd year. The tablet, T. G. Pinches' copy of which was published by Sachs (1955), is vary badly damaged. As discussed in Section 2.2 above, Sachs (1955) dated this tablet to the reign of Nabonassar, making it the earliest known observational text from Babylon. However, the date has been questioned by Huber (1973), and so it is appropriate to discuss its dating in detail.

I give below Prof. H. Hunger's translation of the tablet:

0 At the command of Bel and Beltija may it go well.
1 1,40. Accession year [of ...]
2 Month XII, (after) 5 month, the 14th, morning watch, ... [...]
3 2,10. Year 1. Month VI, [the 1]5th (?), onset (?). It began in the north [...]
4 [...] the south wind blew. It set eclipsed. Month VI was in[tercalary.]
5 [Month XI, the 1]4th, onset (?). 1,40° remained to clearing.
6 [Year 2. Month] V, the 14th, it made a total (eclipse).
7 [Month XI,] omitted.
8 [Year 3. Month V, omitt]ed. Month VI was intercalary.
9 [...] total (?) [...]

The essential observations in attempting to obtain the date of this tablet are that in month XII of the accession year of an unknown king, there was a lunar eclipse in the latter part of the night. This was followed by a lunar eclipse in month VI which set whilst it was still eclipsed. In month XI, there was another lunar eclipse, and then in the following month V, there was a total lunar eclipse. It is very unusual for four lunar eclipses to be visible in a row, and so for this to happen at the beginning of a king's reign is a very rare event, and there should be a good chance that the tablet is datable.

Huber (1973) found that there were only three possible dates for the text between 930 BC and 311 BC (after which time accession years were no longer used): 801–800 BC, 747–746 BC, and 693–692 BC. Independently, I have found that between 850 BC and 311 BC only 801–800 BC and 747–746 BC are possible. I will go through each case in detail below.

On the 4th January 801 BC there was a lunar eclipse in the latter part of the night. This was followed six months later by an eclipse on the 29th June 801 BC. This eclipse set during totality. There was a third eclipse on the 23rd December 801 BC, and then a fourth on the 18th June 800 BC. This final eclipse rose just after it began and became total.

On the 5th February 747 BC the Moon was eclipsed. Six months later, on the 1st August 747 BC, the Moon set eclipsed just before it had cleared. A third eclipse was visible on the 25th January 746 BC, and then a fourth on the 21 July 746 BC. This final eclipse was total, but only rose above the ground just as it began to clear. It is therefore questionable as to whether the total phase of this eclipse could have been seen.

The first set of dates, that of 801–800 BC, gives the best fit to the observation. However, they would suggest that the first month of the Babylonian year began around the 20th January. Typically, the Babylonian year began around end of March or the beginning of April. The second set of dates would result in a Babylonian year beginning around the 20th February, which, whilst still being rather early, is more plausible than the 20th of January. It is also known that 747 BC was the accession year of Nabonassar, which would fit the mention of an accession year in line 1. Unfortunately, the Babylonian chronology of the period around 800 BC is insufficiently well known to comment as to whether 801 BC was also an accession year. I am therefore forced to tentatively accept Sachs' (1955) date for LBAT 1413 of 747–746 BC.

2.4 Units of Time

The earliest unit of time attested in Babylonian sources is the EN.NUN, translated as "watch".[21] Each day contained sixes watches, three for the day and three for the night. Thus the watch was a seasonal time unit; it varied in length both with the time of year and with whether it was during the night or day. At the equinox, the day and night watches were equal in length. This length of one sixth of a day was defined to be equal to 2 KAS, to be read *bēru*. The *bēru* is an equinoctial unit of time; it does not vary in length with the seasons. The original definition of the *bēru* was as a distance of length, corresponding to about seven miles, but it also came to be a measure of the time it takes to travel this distance (Neugebauer 1941).

The *bēru* was divided into thirty smaller units called UŠ. There were 360 UŠ in a day and so one UŠ was precisely equal to 4 minutes of time (Stephenson & Fatoohi 1994b). The UŠ is therefore equivalent to the "time-degree" used by Ptolemy, and so it has become customary to render the term as "degree" in translations. The UŠ was itself subdivided in sixty parts called GAR, probably to be read as *nindan*. By the Late Babylonian period, the UŠ had become the fundamental unit of time used in both mathematical and non-mathematical astronomy.

From the Old Babylonian period there a number of mathematical problems that have been interpreted as referring to the outflow from a clepsydra (Thureau-Dangin 1937). Clepsydras are also mentioned in a diviner's manual in the context of measuring time intervals during lunar observations (Oppenheim 1974), and so it seems likely that they were used extensively in Babylon.[22] However, it is not known exactly what form the clepsydras took. The situation is made additionally confusing by a number of Babylonian tables which record the length of the night throughout the year. These tables vary in the number of intervals into which the year was divided, but all of them fall into one of two categories, that is they are based on the assumption that the ratio between the longest and the shortest night is either 2:1 or 3:2. The former ratio is attested in early texts such as MUL.APIN and *Enūma Anu Enlil*,[23] whilst the latter is also attested in MUL.APIN, and in other works such as i.NAM.giš.ḫur.an.ki.a.[24] Neugebauer (1947) and others have tried to reconcile these two ratios by arguing that the 2:1 ratio was not a ratio of time, but of the weight of water contained in a cylindrical clepsydra; however, Pingree & Reiner (1977) discovered a tablet from the seventh century BC which shows that this is incorrect — the 2:1 ratio indeed referred to time. This ratio is very inaccurate for the latitude of Babylon, and it is hard to see how any clock could have measured it. 3:2 is much closer to the true ratio, and by the Seleucid period the 2:1 ration had been abandoned.

To add further confusion to the matter is the statement in Herodotus that "knowledge of the sundial

[21] Watches are found, for example, in the omen series *Enūma Anu Enlil* (Rochberg-Halton 1988: 44–47), and in the letters and reports sent to the Assyrian king (Parpola 1970; Hunger 1992).

[22] Although there exist tables which have been interpreted as referring to measuring time by use of a gnomon, devices such as this could not have been used during the night.

[23] MUL.APIN has been published by Hunger & Pingree (1989), and the relevant parts of *Enūma Anu Enlil* by Al-Rawi & George (1992).

[24] i.NAM.giš.ḫur.an.ki.a has been published by Livingstone (1986).

and the gnomon and the twelve divisions of the day came into Greece from Babylon."[25] This seems to suggest that seasonal hours were used in Babylon, as well as the equinoctial time systems just discussed. However, there is only a small amount of evidence that this was the case. Pingree & Reiner (1977) have interpreted their tablet from the seventh century BC as a table giving the number of UŠ and *nindan* in a seasonal hour. Similarly, Fotheringham (1932) claimed that there was a table for converting from *bēru* and UŠ to seasonal hours on a small, badly damaged fragment that has become known as the "Ivory Prism".[26] Finally, Rochberg-Halton (1989a, 1989b) has claimed that seasonal hours were used in some of the Babylonian horoscopes produced in the Seleucid period. van der Waerden (1951) has called these seasonal hours "popular units of time" which were used by people in their everyday lives, as opposed to the *bēru* and UŠ which were "astronomical units of time" used by the astronomers. However, there is such limited evidence for the use of seasonal hours in Babylon that I would disagree with his conclusions, and suggest that if there was any "popular" unit of time then it was the watch which is well attested in the literature.[27]

As I mentioned in Section 2.3 above, the Babylonians began their day at sunset. However, they did not measure all times from this point. Instead, the day was divided into four parts: sunset to midnight, midnight to sunrise, sunrise to midday, and midday to sunset. Time was measured relative to sunrise or sunset within each division, that is as a number of UŠ after sunset (GE_6 GIN), before sunrise (GE_6 *ana* ZALAG), after sunrise (ME NIM), or before sunset (*ana* ŠÚ *šámaš*) (Neugebauer & Sachs 1967). To my knowledge, nowhere in Babylonian literature is it defined what is meant by sunrise or sunset. Britton (1992) has assumed that it was when the middle of the Sun was crossing the horizon. However, most cultures have defined sunrise or sunset to be the moment when the upper limb of the Sun crosses the horizon, and so this has been assumed by many other authors. Fortunately, it is possible to determine with some confidence which definition was adopted by the Babylonians from their lunar six measurements.

Some years ago, the late Prof. A. J. Sachs compiled an extensive list of lunar six measurements and predictions from the Astronomical Diaries and the Goal-Year Texts dating from after 300 BC. This unpublished manuscript has formed the basis of the following investigation. To supplement it I have extracted many further lunar six records from the earlier Diaries, and from two tablets, LBAT 1431[28] and LBAT 1433, which contain collections of lunar six data from parts of the years 323–319 BC and 241–239 BC respectively. Drawings of these tablets by T. G. Pinches have been published by Sachs (1955). Due to the scarcity of data before 400 BC, only records from after this date will be considered. Furthermore, only those lunar six timings that appear to have been measured have been considered.[29]

Initially assuming that sunrise and sunset, and moonrise and moonset, were defined as the moment when the upper limb of the luminary crossed the horizon, in Figure 2.2 I show the error in each of the measured lunar six intervals. The mean value of the error in each case in shown as the dotted line on the plot. Unsurprisingly, the lunar six measurement made around new Moon have greater errors than

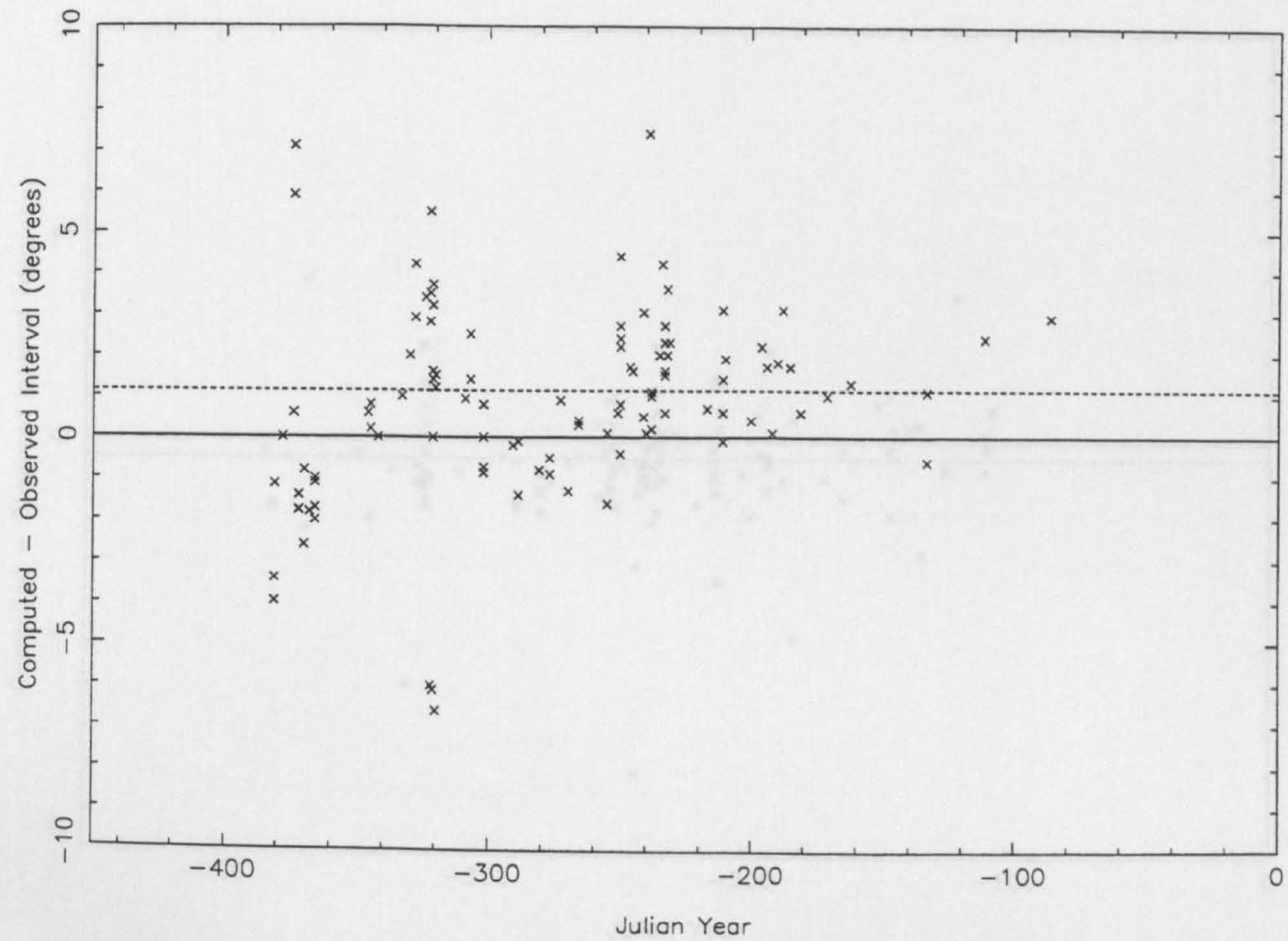
[25] *Historia*, II, 109; trans. de Sélincourt (1979: 169).

[26] Fotheringham's reconstruction of the Ivory Prism was published by Langdon (1935), and also discussed by Smith (1969). Fotheringham's interest in the Ivory Prism was in the possibility of its use in the eclipse records reported by Ptolemy in his *Almagest*, and so I will defer further discussion of it until Chapter 3.

[27] Of course, a seasonal hour is simply a quarter of a watch, but I do not think it was ever extensively used as a unit of time in its own right.

[28] The lunar six data recorded on LBAT 1431 have previously been investigated by Stephenson (1974) who found evidence for systematic clock drifts in the measurement of each of the individual of the lunar six. He concluded that the Babylonian astronomers may have used a slightly different clock, possibly labeled for the purpose, to measure each of the six intervals.

[29] The lunar six measurements may be divided into three groups: those said to have been measured using the term *muš*, those said to have been not seen using the term NU PAP, and those that have no comment attached. Unless there is some mention of bad weather in the record, I have assumed that those timings in the third of these categories were measured. This may have caused some predicted material to be included in the analysis, but as there is not significant change in the result if this group is ignored, it would appear that, on the whole, these do indeed represent measured lunar six values.



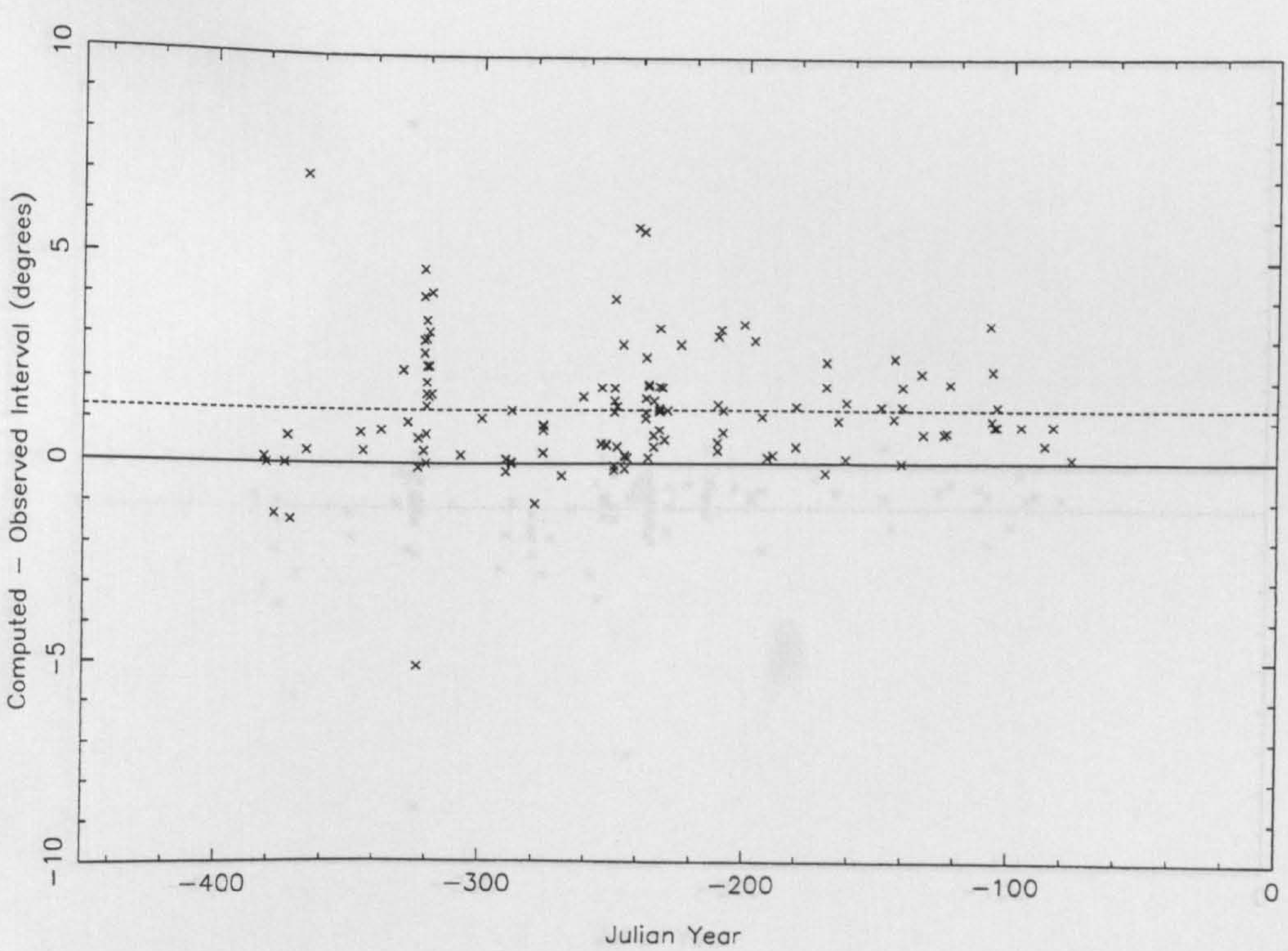
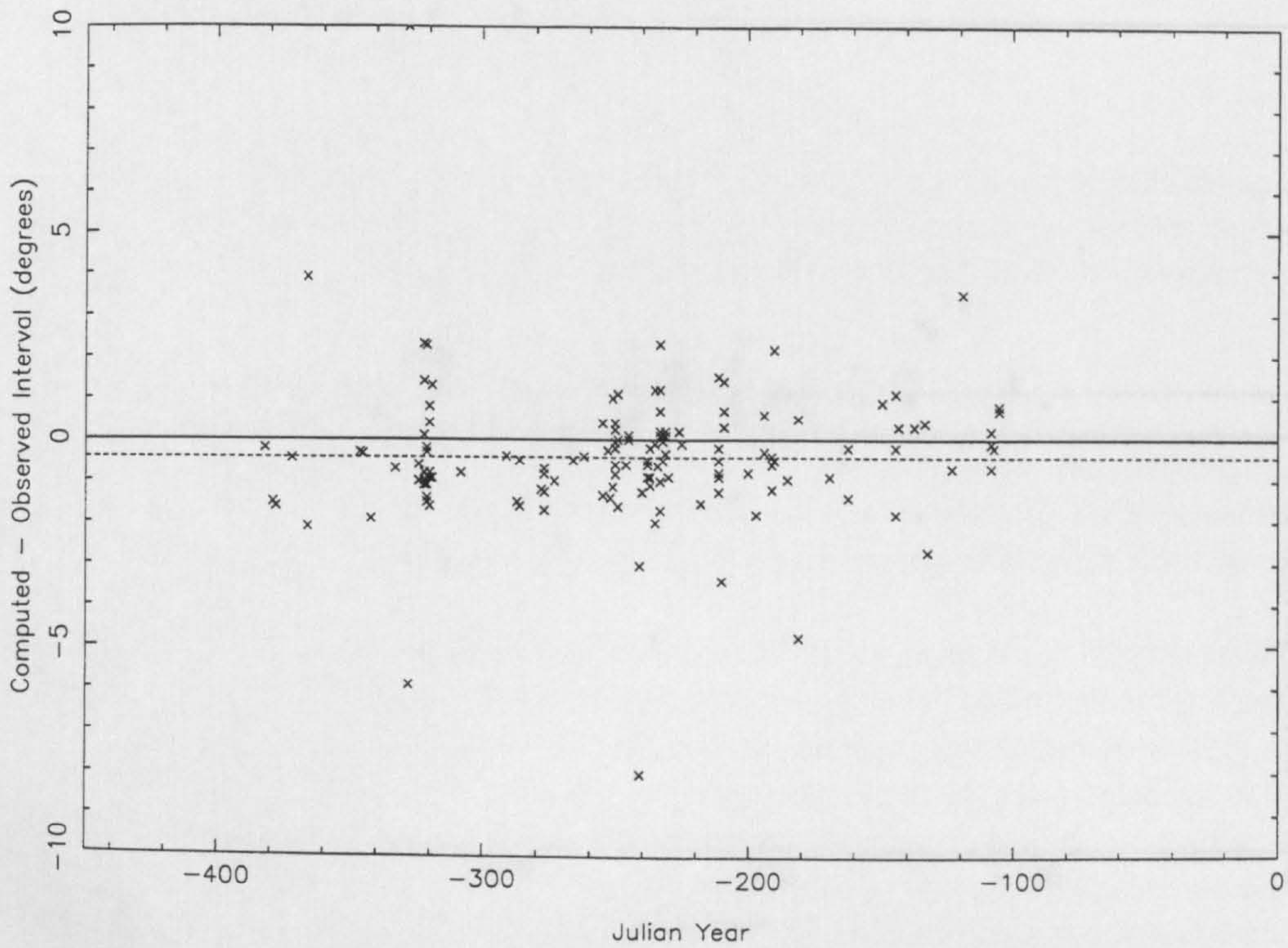


Figure 2.2: The error in the measured lunar six intervals (a, top) *na* and (b, bottom) ŠÚ.



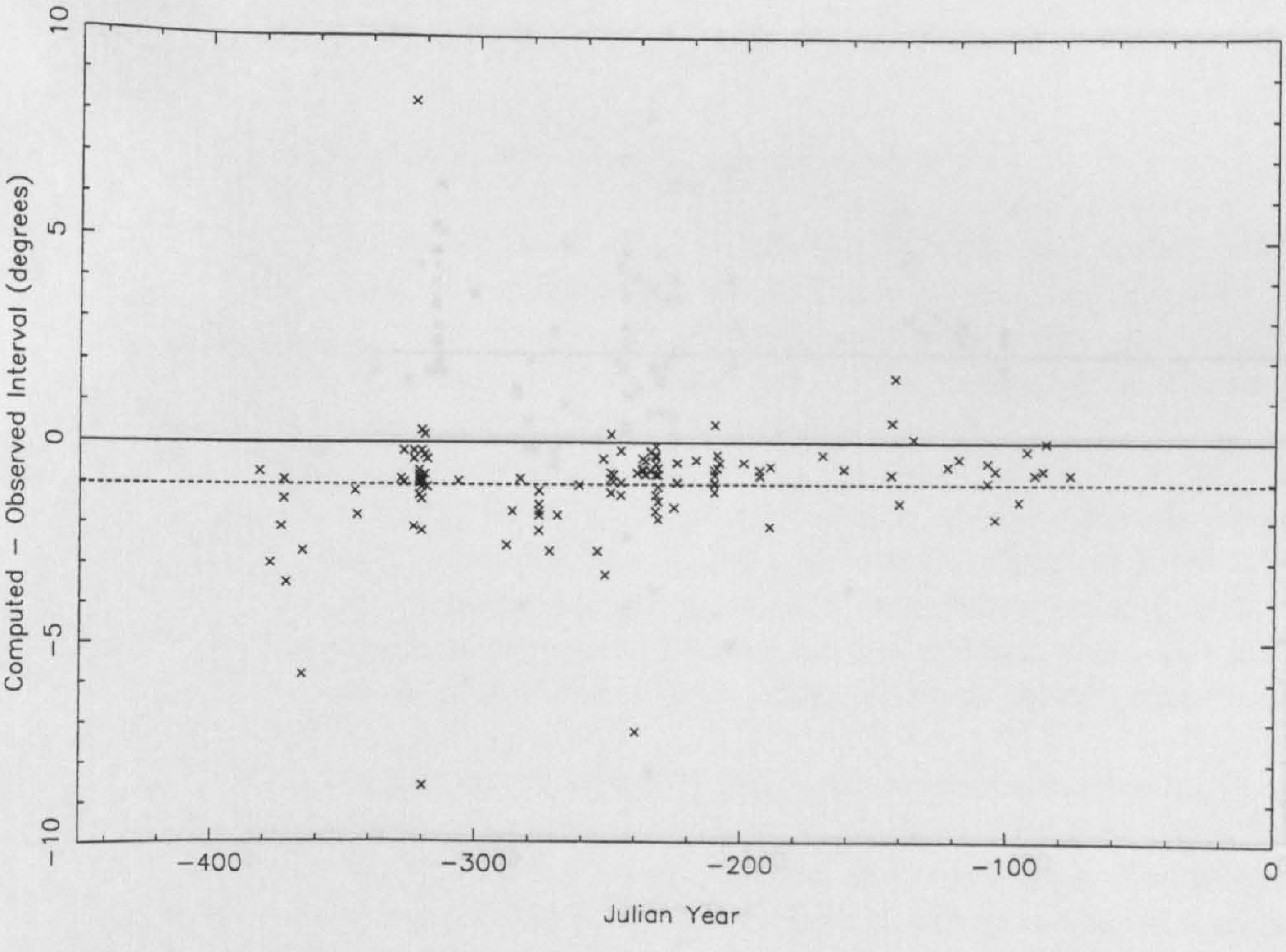


Figure 2.2 (cont.): The error in the measured lunar six intervals (c, top) *na* and (d, bottom) ME.

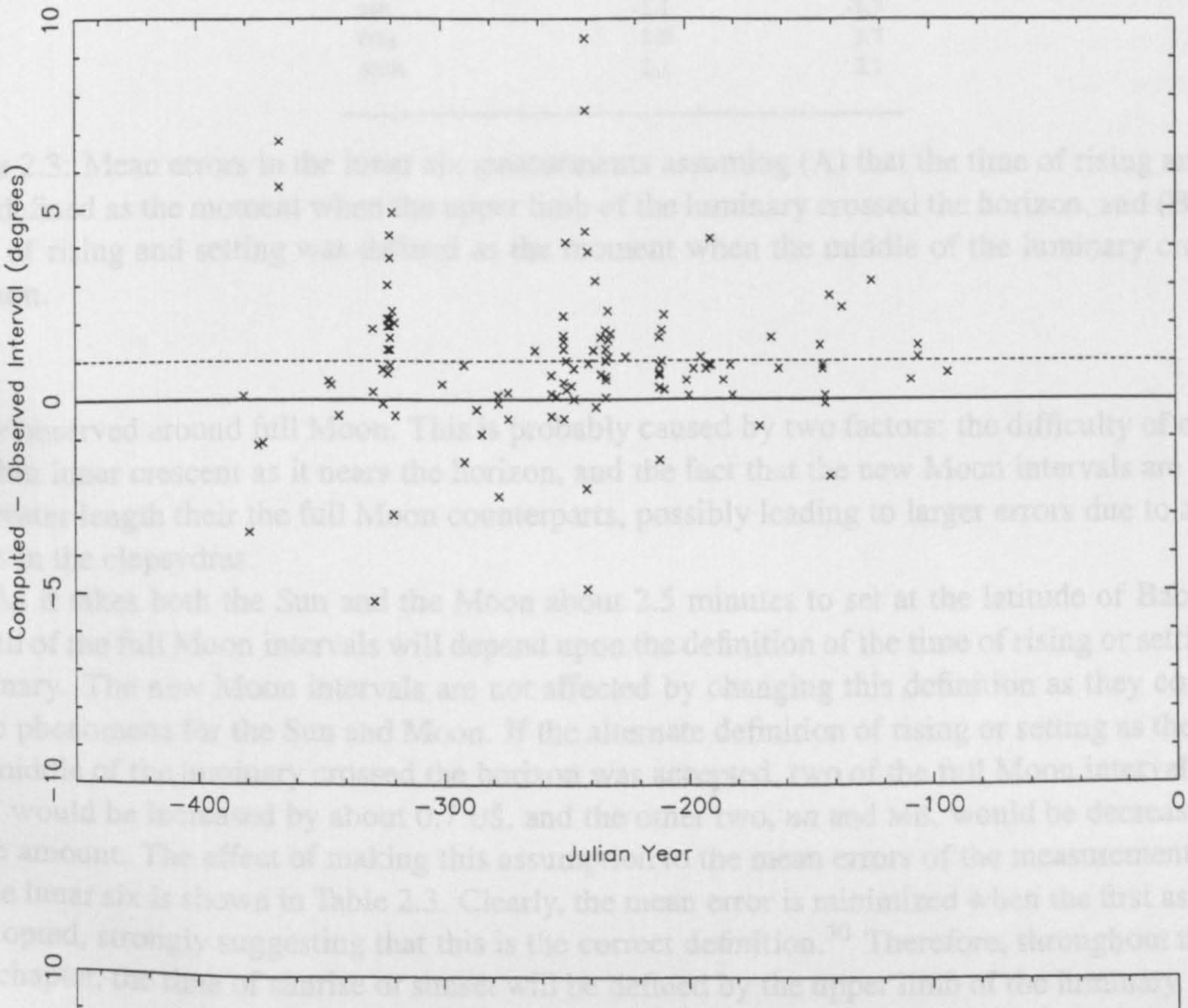


Figure 2.2 (cont.): The error in the measured lunar six intervals (e, top) GE_6 and (f, bottom) KUR.

Lunar Six	Mean Error A (°)	Mean Error B (°)
na	1.1	1.1
ŠÚ	1.3	2.0
na	-0.4	-1.1
ME	-1.1	-1.7
GE_6	1.0	1.7
KUR	2.1	2.1

Table 2.3: Mean errors in the lunar six measurments assuming (A) that the time of rising and setting was defined as the moment when the upper limb of the luminary crossed the horizon, and (B) that the time of rising and setting was defined as the moment when the middle of the luminary crossed the horizon.

those observed around full Moon. This is probably caused by two factors: the difficulty of observing the thin lunar crescent as it nears the horizon, and the fact that the new Moon intervals are typically of greater length their the full Moon counterparts, possibly leading to larger errors due to any clock drifts in the clepsydras.

As it takes both the Sun and the Moon about 2.5 minutes to set at the latitude of Babylon, the length of the full Moon intervals will depend upon the definition of the time of rising or setting of the luminary. The new Moon intervals are not affected by changing this definition as they concern the same phenomena for the Sun and Moon. If the alternate definition of rising or setting as the moment the middle of the luminary crossed the horizon was accepted, two of the full Moon intervals, ŠÚ and GE_6, would be increased by about 0.7 UŠ, and the other two, *na* and ME, would be decreased by the same amount. The effect of making this assumption to the mean errors of the measurements of each of the lunar six is shown in Table 2.3. Clearly, the mean error is minimized when the first assumption is adopted, strongly suggesting that this is the correct definition.[30] Therefore, throughout the rest of this chapter, the time of sunrise or sunset will be defined by the upper limb of the luminary.

2.5 Eclipse Records in Late Babylonian History

Late Babylonian eclipse records are found in all types of the NMAT texts: Astronomical Diaries, Goal-Year Texts, Lists and Individual Reports, Almanacs, and Normal Star Almanacs. All of the references to lunar and solar eclipse observations and predictions in these texts are listed in Appendix A. In the present section I shall outline the terminology used in describing the eclipses, and make some general comments on the records contained in each type of source.

In the Late Babylonian Astronomical Texts, observed eclipses are denoted by either AN-KU_{10} *sin*, for a lunar obscuration, or AN-KU_{10} *šamáš*, for a solar obscuration. If the eclipse was predicted rather than observed, then the order was reversed: *sin* AN-KU_{10}, for a lunar eclipse, or *šamáš* AN-KU_{10}, for a solar eclipse. Furthermore, predicted eclipses are usually described as being *šá* DIB ("omitted") meaning that they were not expected to prove visible as the Sun or Moon was below the horizon at the predicted time of the eclipse, or *ki* PAP NU IGI ("watched for, but not seen") when the anticipated eclipse failed to appear.

Both observations and predictions of lunar and solar eclipses are recorded in the Diaries, Goal-Year Texts, and the Eclipse Texts. As mentioned in Section 2.2 above, it appears that eclipse records in the Goal-Year Texts and the Eclipse Texts were compiled from the Diaries. The Eclipse texts are of particular interest for not only are they the largest archive of eclipse records in Late Babylonian history, they may also offer some information on the schemes used by the Babylonian astronomers to

[30]The remaining errors are presumably due to the inherent inaccuracies of the clepsydras used for the measurements.

predict future eclipses.[31] The Eclipse Texts may be divided into three categories: individual reports, straight-forward lists of consecutive eclipses and eclipse possibilities, and lists arranged in Saros cycles (Walker 1997). Among the tablets in this final category are three tablets, LBAT 1414, LBAT 1415 + 1416 + 1417, and LBAT 1419, which Walker (1997) has suggested were part of a set compiled by a single scribe and containing lunar eclipses and eclipse possibilities from twenty-four Saros cycles starting in 747 BC. From the preserved fragments of these texts there are three observations of lunar eclipses that we can compute were only penumbral. In one these cases, the Moon is said to be near β Capricorni, but computations show that the Moon was more than 80° away from this star at the time of the eclipse. It would therefore appear that these eclipses were wrongly filed in the compilation. However, if Walker (1997) is correct in his suggestion that the tablets formed part of the same series, an idea which I find more than plausible, then the whole compilation contained over 900 entries, and so it is not surprising that there would be the occasional scribal mistake.

The observed accounts in the Diaries, Goal-Year Texts, and Eclipse Texts usually give details such as the time of the eclipse measured relative to sunset or sunrise, an estimate of the magnitude of the eclipse expressed in fingers or twelfths of the lunar or solar diameter, a measurement of the duration of the eclipse and its phases, and sometimes meterological remarks.[32] The visibilities of stars and planets may also be noted during the eclipse. For example, on the 1st August 226 BC:

> "Night of the 14th, moonrise to sunset: 4°, measured (despite) mist; at 52° after sunset, when α Cygni culminated, lunar eclipse; when it began on the east side, in 17° nighttime it covered it completely; 10° nighttime maximum phase; when it began to clear, it cleared in 15° nighttime from south to north; in (its) onset it was slow, in (its) clearing it was fast; 42° onset, maximum phase, and clearing; its eclipse was red; (in) its eclipse, a gusty north wind blew; (in) its eclipse, all the planets did not stand there; 5 cubits behind δ Capricorni it became eclipsed."
>
> [BM 33655, Rev. 4–8; trans. Sachs & Hunger (1988: 141)]

It is not immediately clear in this example whether the time of 52° after sunset refers to the beginning, the middle, or the end of the eclipse. However, it seems most natural to suppose that it is the time of the start of the eclipse, and this is confirmed by, for example, the record of the lunar eclipse on the 22nd November 353 BC:

> "Month VIII, the 14th. When it began on the south and east side, in 23° all was covered. 18° maximal phase. (After) 16° of night, one-fourth on the east side cleared; it set eclipsed. The eclipse was red. $1\frac{1}{2}$ cubits behind ζ Tauri it was eclipsed. During the eclipse Saturn stood there; the remainder of the planets did not stand there. The north wind which was slanted to the west blew. At 47° before sunrise."
>
> [LBAT 1414, Rev. III', 2'–10'; trans. Sachs & Hunger (1998)]

In this example, the Moon was totally eclipsed. It took 23° for the eclipse to become total, and totality lasted for 18°. 6° after the end of totality, the Moon set. Therefore, first contact is 23° + 18° + 6° = 47° before the Moon set, the same time as stated at the end of the report as moonset and sunrise were more or less simultaneous on this date. Hence it may be inferred that, in the general case, the time stated in a report of an eclipse observation is the time that the eclipse began.

In the lunar eclipse reports, it is customary for the Babylonian astronomers to give timings of the durations of the following phases: onset, maximal phase, and clearing. For total eclipses it is easy to understand that these relate to the time between the start of the eclipse and totality, the duration of totality, and the end of totality to the end of the eclipse. However, the Babylonian astronomers also give timings of these three phases for partial lunar eclipses. Thus, they defined a "maximal phase" for a partial eclipse when they were unable to detect any change in the extent of the shadow. This

[31] I will discuss this aspect of the Eclipse Texts in Section 2.8 below. A fuller description of the structure of the Eclipse Texts will be given in my forthcoming contribution to Sachs & Hunger (1998).

[32] These remarks concern not only factors such as clouds that may have affected the observation, but also wind directions which play an important role in the astrological interpretation of the eclipse.

is purely a physiological effect dependent of the acuity of the eye of the observer, and so it will be impossible to compare any timings of such phases with modern computations.

There are only two mentions of a maximal phase for a solar eclipse; one is in the report of the total eclipse on the 15th April 136 BC, and the other is in the description of the eclipse on the 30th June 10 BC. The record of the eclipse on the 15th April 136 BC is one of the most remarkable of all historical eclipse observations for it is the only example of a detailed timed observation of a total solar eclipse in the ancient world. It is recorded on two tablets, a Diary (LBAT *429) and a Goal-Year Text (LBAT 1285):

> "The 29th, at 24° after sunrise, solar eclipse; when it began on the south and west side, [... Ven]us, Mercury, and the Normal stars were visible; Jupiter and Mars, which were in their period of invisibility, were visible in its eclipse [...] it threw off (the shadow) from west and south to north and east; 35° onset, maximal phase, and clearing."
>
> [LBAT *429, Rev. 13'–15'; trans. Sachs & Hunger (1996: 185)]
>
> "Month XII_2 29. Solar eclipse, beginning on the south-west side. In 18° of day ... it became total. At 24° after sunrise."
>
> [LBAT 1285, Rev. 24–28; trans. Huber (1974: 93–94)]

The fact that the report of the eclipse on the 30th June 10 BC, which is quoted above in Section 2.3.1, also includes a timing of a maximal phase strongly suggests that it is a total eclipse. Other solar eclipse reports merely report the durations of two phases of the eclipse: the beginning to the middle (or more likely maximum) of the eclipse, and from the middle to the end. For example, the report of the eclipse on the 31st January 254 BC:

> "The 28th, 56° before sunset, solar eclipse; when it began, in 12° of daytime [...] when it began [to cl]ear, it cleared from south to north in 11° daytime; 23° onset and clearing; during its eclipse blew the west wind which was slanted to the north."
>
> [LBAT 596 + 258, Rev. 11–12; trans Sachs & Hunger (1989: 29)]

It is interesting to note that in a number of the examples where durations of onset and clearing are preserved, the two time intervals do not match. This provides strong evidence that the times were indeed measured, for if they were calculated by the Babylonian astronomers, it is unlikely that they would have obtained different durations for these phases.

In complete contrast to the detailed descriptions of the observed eclipses recorded in the Diaries,[33] accounts of predicted eclipses are usually very brief stating no more than the time that the eclipse was expected to have occurred, and whether it had been watched for and not seen, or had been omitted. For example, the account of the predicted eclipse on the 26th May 194 BC is typically brief:

> "Night of the 29th, at 1,17° after sunset, solar eclipse which was omitted."
>
> [LBAT *322, Rev. 5'; trans. Sachs & Hunger (1989: 277)]

Comparison with the preceeding examples of observational records suggests that the eclipse was expected to begin at 1,17° (= 77°) after sunset. There are also a number of examples where the record contains a mixture of an observation and a prediction. For example, on the 19th of June 67 BC the Moon was observed to rise eclipsed. The end of the report gives the time when the eclipse began, which clearly must be a prediction:

> "Year 180, which is year 244, Arsaces king and Piriwuštanā, his wife, queen. Month X, night of the 15th, moonrise to sunset: 1°, measured (despite) mist. When the Moon came out, two thirds of the disk on the north and east side were covered. 6° of night maximal phase. When it began to clear, it cleared in 16° of night from south and east to north and west. 23° maximal phase

[33] It is trivial to note that, of course, not all of the observed accounts will include all of the items I have discussed here, and furthermore that many reports are only partially preserved.

and clearing. Its eclipse had the "garment of the sky". In its eclipse, the north wind blew. In its eclipse, Venus, Saturn and Sirius stood there; the remainder of the planets did not stand there. $1\frac{1}{2}$ cubits in front of α Leonis it was [eclips]ed. At 16° before sunset."

[LBAT 1448; trans. Sachs & Hunger (1998)]

As I have mentioned in Section 2.2 above, the Almanacs and Normal Star Almanacs contain purely predicted material. Thus the eclipse records they contain are advance predictions that are either to be watched for, or which will be omitted. Occasionally, a preserved Diary or other source will contain an observation of the eclipse that was predicted in an Almanac or Normal Star Almanac.[34] For example, the lunar eclipse on the 3rd September 134 BC, was predicted in the Almanac LBAT 1134, and was recorded as observed in the Diary LBAT *435:

"Night of the 15th, 1 *bēru* after sunset, lunar eclipse."

[LBAT 1134, Obv. 12']

"[...] when it began [to clear], in 10° night it cleared from east to west ... [...] at 32° after sunset."

[LBAT *435, Obv. 8'–9'; trans. Sachs & Hunger (1996: 199)]

It is interesting to note that in this case the Babylonian astronomers would have noted only a small difference between their predicted and observed times.

2.6 Accuracy of the Observed Times

Of the many reports of lunar and solar eclipses in Late Babylonian history, more than one-hundred contain a measurement of either the time interval between the beginning of the eclipse and sunrise or sunset, or the duration of the phases of the eclipse, or in some cases both. By comparing these measurements with modern computations it is possible to evaluate the accuracy with which the Babylonian astronomers were able to time the eclipses, and to note any trends in the errors in the clocks that they used. Previously, Stephenson & Fatoohi (1993) have analysed many of the lunar eclipse timings and found some evidence for clock drifts of about 13%. However, their analysis contains significant errors, in part caused by the use of a preliminary approximation to the Earth's rotational clock error, ΔT, and in part by double counting some of their data.

Tables 2.4 and 2.5 list respectively the lunar and solar eclipses for which at least one timing of either the beginning of the eclipse or a phase duration are preserved. Also given are the equivalent times as deduced from modern computations. As I mentioned in Section 2.5 above, a number of records of partial lunar eclipses contain estimates of the duration of a maximal phase when no apparent change in the extent of the eclipse could be detected. However, as this is a physiological effect dependent on the observer, these phases cannot be compared with computation. Instead, if the onset and clearing phases have also been reported, then the three intervals have been added together to give the total duration of the eclipse. If the total duration and all of the phases of an eclipse are reported, then only the individual phases are given, except as noted above. In all cases, times in these tables are given in UŠ, even if the original record quotes the times in *bēru*.

It is immediately evident from Table 2.4 that before about 570 BC, most of the measured times appear to have been rounded to the nearest 5°. This suggests that the Babylonian astronomers had a growing confidence in their timing methods after this period. However, from Figure 2.3, which shows the error in all of the measured lunar and solar eclipse times, it is immediately clear that there was no corresponding improvement in the accuracy of the times. This implies that any changes in the clocks used by the Babylonian astronomers around 570 BC resulted only in an improvement in precision of quoted measurement and not in real accuracy. In fact from Figure 2.3, it is clear that over

[34] Unfortunately, due to the vagaries of preservation, there is only a small amount of overlap between years contained on dated Diaries, and those on the dated Almanacs or Normal Star Almanacs. See Hunger (1998).

Date	Observed Details: 1st Contact Interval	Observed Phase Durations: 1st to 2nd	2nd to 3rd	3rd to 4th	1st to 4th	Computed Details: 1st Contact Interval	Computed Phase Durations: 1st to 2nd	2nd to 3rd	3rd to 4th	1st to 4th
-685 Apr 22	100° after sunset	-	-	-	-	111.00° after sunset	-	-	-	-
-684 Oct 3	20° after sunset	-	-	-	-	16.75° after sunset	-	-	-	-
-631 May 24	-	-	-	-	20°	-	-	-	-	19.25°
-602 Oct 27	45° after sunset	-	-	-	45°	37.25° after sunset	-	-	-	38.75°
-600 Apr 11	95° after sunset	-	-	-	-	93.25° after sunset	-	-	-	-
-598 Feb 20	105° after sunset	-	-	-	-	88.25° after sunset	-	-	-	-
-593 May 23	10° after sunset	-	-	-	-	24.00° after sunset	-	-	-	-
-591 Apr 2	-	-	-	-	36°	-	-	-	-	36.00°
-587 Jan 19	20° before sunrise	-	-	-	-	30.25° before sunrise	-	-	-	-
-586 Jan 8	35° before sunrise	-	-	-	-	32.25° before sunrise	-	-	-	-
-579 Aug 15	45° after sunset	-	-	-	-	49.50° after sunset	-	-	-	-
-576 Dec 8	105° after sunset	-	-	-	-	110.00° after sunset	-	-	-	-
-575 Jun 3	40° before sunrise	-	-	-	-	31.50° before sunrise	-	-	-	-
-572 Apr 2	90° after sunset	-	-	-	-	90.25° after sunset	-	-	-	-
-561 Mar 3	90° after sunset	-	25°	18°	-	82.50° after sunset	-	26.00°	15.75°	-
-554 Oct 6	55° after sunset	17°	28°	20°	-	55.75° after sunset	16.25°	24.50°	16.25°	-
-536 Oct 17	14° before sunrise	-	-	-	-	20.00° before sunrise	-	-	-	-
-525 Sep 17	60° after sunset	18°	14°	-	-	68.75° after sunset	14.50°	23.75°	-	-
-500 Nov 7	77° after sunset	15°	25°	25°	-	69.25° after sunset	16.75°	23.50°	16.75°	-
-482 Nov 19	10° before sunrise	-	-	-	-	6.75° before sunrise	-	-	-	-
-464 Jun 5	-	-	-	-	40°	-	-	-	-	46.25°
-423 Sep 28	50° after sunset	-	-	-	50°	53.50° after sunset	-	-	-	35.00°
-409 Dec 21	-	-	-	-	60°	-	-	-	-	47.75°
-407 Oct 31	15° after sunset	-	-	-	27°	14.25° after sunset	-	-	-	22.75°
-406 Oct 21	48° before sunrise	-	-	-	56°	49.25° before sunrise	-	-	-	55°
-405 Apr 15	-	25°	19°	-	-	-	16.25°	18.50°	-	-
-405 Oct 10	14° before sunrise	-	-	-	-	9.25° before sunrise	-	-	-	-
-396 Apr 5	48° after sunset	-	-	-	27°	48.75° after sunset	-	-	-	16.25°
-377 Apr 6	-	15°	21°	19°	-	-	15.75°	19.00°	15.75°	-
-370 May 17	66° after sunset	-	-	-	-	57.00° after sunset	-	-	-	-
-370 Nov 11	30° after sunset	21°	20°	21°	-	38.50° after sunset	17.00°	21.00°	17.00°	-
-363 Jun 29	40° before sunrise	-	-	-	-	33.25° before sunrise	-	-	-	-
-363 Dec 23	14° before sunrise	-	-	-	-	11.75° before sunrise	-	-	-	-
-362 Jun 18	41° before sunrise	-	-	-	-	37.00° before sunrise	-	-	-	-
-352 Nov 22	47° before sunrise	23°	18°	-	-	41.50° before sunrise	17.00°	21.00°	-	-
-345 Jan 14	-	-	-	-	23°	-	-	-	-	23.75°
-316 Jun 18	10° after sunset	-	-	-	-	15.75° after sunset	-	-	-	-

Table 2.4: Lunar eclipse timings.

Date	1st Contact Interval	Phase Durations 1st to 2nd	2nd to 3rd	3rd to 4th	1st to 4th	1st Contact Interval	Phase Durations 1st to 2nd	2nd to 3rd	3rd to 4th	1st to 4th
-316 Dec 13	44° after sunset	19°	5°	16°	-	54.00° after sunset	17.00°	20.75°	17.00°	-
-307 Jul 9	10° before sunrise	-	-	-	-	9.75° before sunrise	-	-	-	-
-283 Mar 17	-	22°	22°	-	65°	-	20.00°	11.00°	-	45.25°
-272 Feb 16	-	-	19°	22°	-	-	-	19.25°	15.75°	-
-239 Nov 3	3° before sunrise	-	-	-	-	1.00° *after* sunrise	-	-	-	-
-238 Apr 28	80° after sunset	-	-	-	40°	61.25° after sunset	-	-	-	35.50°
-225 Aug 1	52° after sunset	17°	10°	15°	-	70.75° after sunset	16.75°	16.00°	16.75°	-
-214 Dec 25	15° after sunset	21°	16°	19°	-	15° after sunset	15.75°	20.75°	15.75°	-
-211 Apr 30	20° before sunrise	-	-	-	-	24.50° before sunrise	-	-	-	-
-211 Oct 24	28° after sunrise	-	-	-	-	62.25° after sunrise	-	-	-	-
-193 Nov 5	12° before sunrise	-	-	-	-	8.00° before sunrise	-	-	-	-
-189 Feb 28	30° before sunrise	-	-	-	-	37.75° before sunrise	-	-	-	-
-188 Feb 17	34° before sunrise	16°	-	-	-	41.75° before sunrise	18.00°	-	-	-
-184 Nov 24	44° after sunset	-	-	-	-	36.75° after sunset	-	-	-	-
-162 Mar 30	85° before sunrise	-	-	-	-	96.25° before sunrise	-	-	-	-
-159 Jan 26	48° after sunset	-	-	-	-	55.25° after sunset	-	-	-	-
-156 Nov 15	-	-	42°	-	-	-	-	24.25°	-	-
-153 Mar 21	4° after sunset	-	-	-	44°	6.50° after sunset	-	-	-	49.50°
-149 Jul 2	-	20°	12°	-	-	-	20.25°	13.00°	-	-
-142 Feb 17	7° after sunset	-	-	-	-	8.75° after sunset	-	-	-	-
-135 Apr 1	30° before sunrise	-	-	-	-	63.75° before sunrise	-	-	-	-
-134 Mar 20	-	-	-	-	60°	-	-	-	-	58.25°
-133 Mar 10	9° before sunrise	-	-	-	-	13.50° before sunrise	-	-	-	-
-133 Sep 3	32° after sunset	-	-	-	-	33.50° after sunset	-	-	-	-
-128 Nov 5	55° before sunrise	-	-	-	40°	55.50° before sunrise	-	-	-	43°
-123 Aug 13	-	19°	24°	19°	-	-	16.75°	24.50°	16.75°	-
-119 Jun 2	66° after sunset	-	-	-	54°	68.75° after sunset	-	-	-	47.75°
-109 Nov 5	25° after sunset	-	20°	-	-	22.00° after sunset	-	25.00°	-	-
-108 May 1	8° after sunset	-	-	-	-	9.25° after sunset	-	-	-	-
-105 Feb 28	66° after sunset	-	-	-	60°	61.00° after sunset	-	-	-	53.00°
-105 Aug 24	50° before sunrise	21°	21°	-	-	44.50° before sunrise	16.50°	25.50°	-	-
-95 Aug 3	57° after sunset	-	-	-	-	63.50° after sunset	-	-	-	-
-86 Feb 28	-	-	-	-	30°	-	-	-	-	33.25°
-80 Apr 21	60° after sunset	-	22°	-	-	49.50° after sunset	-	26.25°	-	-
-79 Apr 10	40° before sunrise	-	-	-	40°	39.75° before sunrise	-	-	-	21.50°
-79 Oct 5	30° after sunset	-	-	-	-	32.50° after sunset	-	-	-	-
-72 Nov 16	37° before sunrise	-	-	-	-	30.50° before sunrise	-	-	-	-
-40 Mar 2	-	21°	-	-	-	-	15.00°	-	-	-

Table 2.4 (cont.): Lunar eclipse timings.

Date	Observed Details				Computed Details			
	1st Contact Interval	Phase Durations 1st to Max	Phase Durations Max to 4th	Phase Durations 1st to 4th	1st Contact Interval	Phase Durations 1st to Max	Phase Durations Max to 4th	Phase Durations 1st to 4th
-368 Apr 11	-	6°	-	-	-	15.00°	-	-
-321 Sep 26	3° before sunset	-	-	-	3.50° before sunset	-	-	-
-280 Jan 30	6° after sunrise	-	-	20°	2.75° after sunrise	-	-	23.25°
-255 Sep 6	-	-	-	32°	-	-	-	39.25°
-253 Jan 31	56° before sunset	12°	13°	-	64.00° before sunset	16.00°	15.00°	-
-248 May 5	90° after sunrise	-	-	-	93.25°	-	-	-
-241 Jun 15	-	-	18°	-	-	-	16.25°	-
-240 Nov 28	-	-	-	30°	-	-	-	36.50°
-194 Jan 6	60° after sunrise	-	-	-	38.25° after sunrise	-	-	-
-189 Mar 14	30° after sunrise	15°	15°	-	31.25° after sunrise	17.75°	19.00°	-
-169 Jul 28	20° before sunset	12°	-	-	19.50° before sunset	11.50°	-	-
-165 May 17	-	13°	-	-	-	23.50°	-	-
-135 Apr 15	24° after sunrise	-	-	35°	26.50° after sunrise	-	-	33.50°
-132 Feb 13	51° before sunset	20°	18°	-	50.50° before sunset	21.75°	19.25°	-
-125 Sep 9	-	-	-	35°	-	-	-	41.00°
-111 Jun 18	-	-	8°	-	-	-	14.25°	-
-88 Sep 29	45° after sunrise	-	-	24°	33.50° after sunrise	-	-	31.50°
-9 Jun 30	90° before sunset	-	-	48°	95.25° before sunset	-	-	40.00°

Table 2.5: Solar eclipse timings.

the whole of the Late Babylonian period, there was no improvement in the accuracy of the eclipse timings. Furthermore, there is no significant difference between the accuracy of the solar eclipse timings and the lunar eclipse timings. This suggests that the same devices were used to time both types of event, and that it was these devices, and not factors such as the difficulty in determining lunar eclipse contacts due to the diffuse nature of the Earth's shadow, which was the limiting factor in the accuracy of timing eclipses.

Figure 2.4 shows the error in the measured times plotted against the month of the year in which they were observed. This should reveal any seasonal influences on the accuracy of the timings. Possible causes of this may include changes in the viscosity of the water used in a clepsydra with the change in temperature, or use of a unit of time that was based upon the inaccurate 2:1 ratio for the longest to the shortest day used by the Babylonians. From Figure 2.4, however, it is clear that there was no significant seasonal effect on the accuracy of the timings. Consequently, as it is unlikely that the two effects mentioned above would cancel each-other out, it would appear that the Babylonians somehow — possibly inadvertently — managed to nullify any changes in the temperature of the water in the clepsydra; perhaps they placed the device inside a room that could be heated if necessary. Furthermore, this provides further proof, if it were needed, that the UŠ was indeed invariant in length. It may also have been expected that there would have been a change in accuracy between the summer months when there is usually little cloud on the horizon at Babylon and sunset or sunset are well defined, and in the winter months when, for example, clouds may have obscured these times. Good weather is never mentioned in the Late Babylonian Astronomical Texts (Sachs 1974), but there are a number of example, such as the report of the lunar eclipse on the 30th April 212 BC, when cloud partially interfered with the observation:

> "... Lunar eclipse, beginning on the south side. Around maximal phase cloudy, not observed. It set eclipsed. At 30° before sunrise."
>
> [LBAT **1237; Rev. 48–53; trans. Huber (1974: 56)]

In this case, presumably the sky cleared sufficiently towards the end of the eclipse for moonset to be seen.

Unlike most early astronomers who made timings of eclipses, the Babylonians did not time all of the contacts of the eclipse relative to the same point. Instead, the time of first contact was measured from either sunrise or sunset, and the other phases of the eclipse were measured relative to this. It is therefore interesting to ask whether the same clocks were used for making each set of measurements. In Figure 2.5, the error in the first contact intervals and in the phase durations are plotted separately against the year. Clearly there does not appear to be any significant difference between the two sets of data. This suggests that the same clocks were used to measure all of the timings associated with the eclipses.

As I have mentioned in Section 2.4 above, it seems most likely that the Babylonians used some form of clepsydra to make their eclipse timings. This suggests that a major source of error in the timings might be due to some form of clock drift, implying that the longer the time interval measured, the greater the error in the measurement might be. This is illustrated by Figure 2.6 which shows the error in the observed timing plotted against the computed time intervals. Clearly, the dispersion of the error appears to increase with the length of the computed interval. This is characteristic of a random error in clock drift. Because this error is random, it is more appropriate to think in terms of the accuracy of the observations (i.e., their error irrespective of whether the times are early or late), rather than of the error in the times. The change in the accuracy with interval can be approximated by fitting a straight line to the absolute values of the errors in Figure 2.6. This line has a slope of about 0.083 degrees per degree of interval and a zero-point of 3.4 degrees. This is illustrated by the two dashed lines in Figure 2.6. The zero-point error suggests that the Babylonian clocks could only be read with an accuracy of about 3.4 degrees.

To summarize, it appears that the Babylonian astronomers used the same clocks to measure the

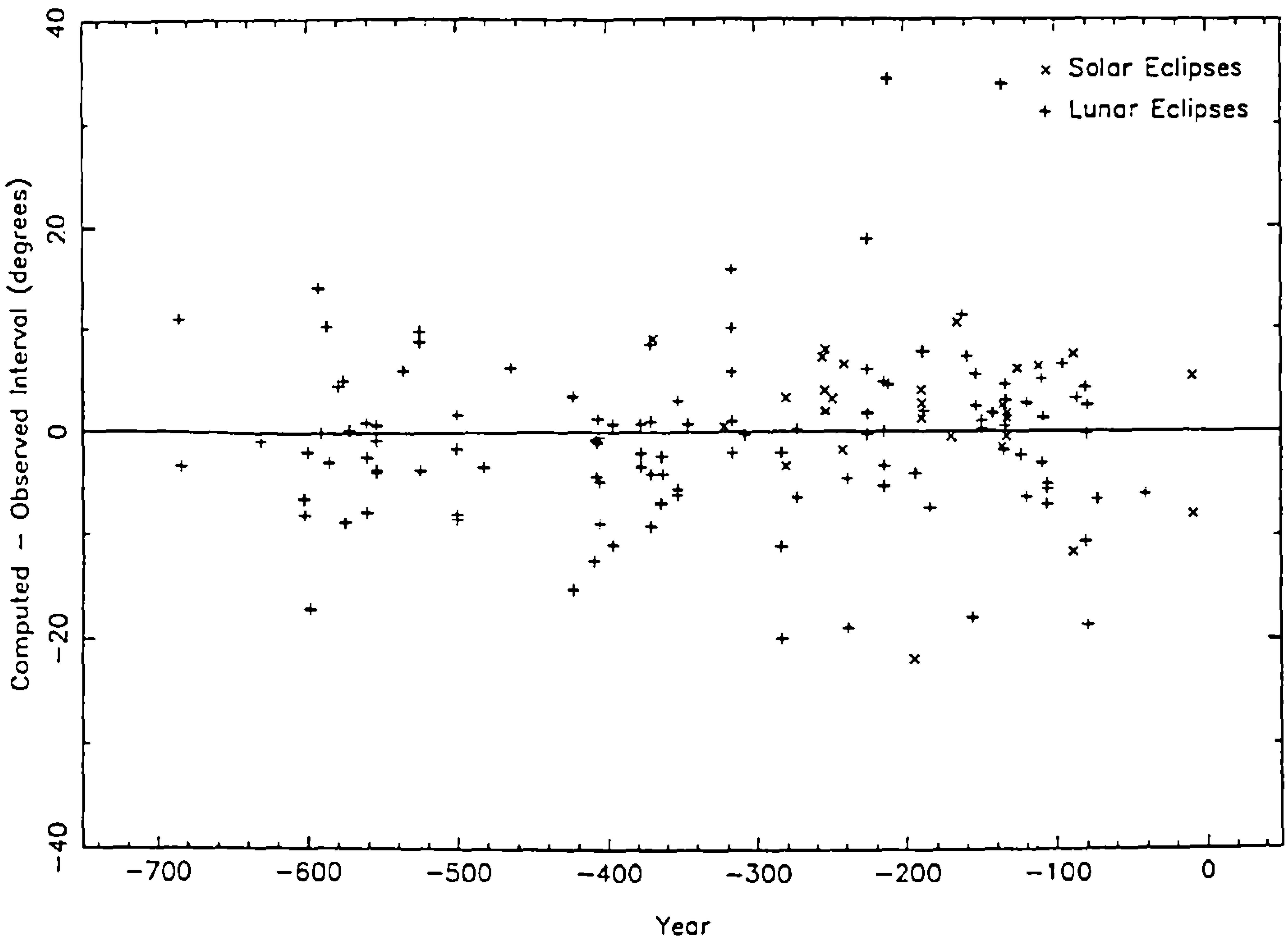


Figure 2.3: The error in the observed solar and lunar eclipse timings over the Late Babylonian period.

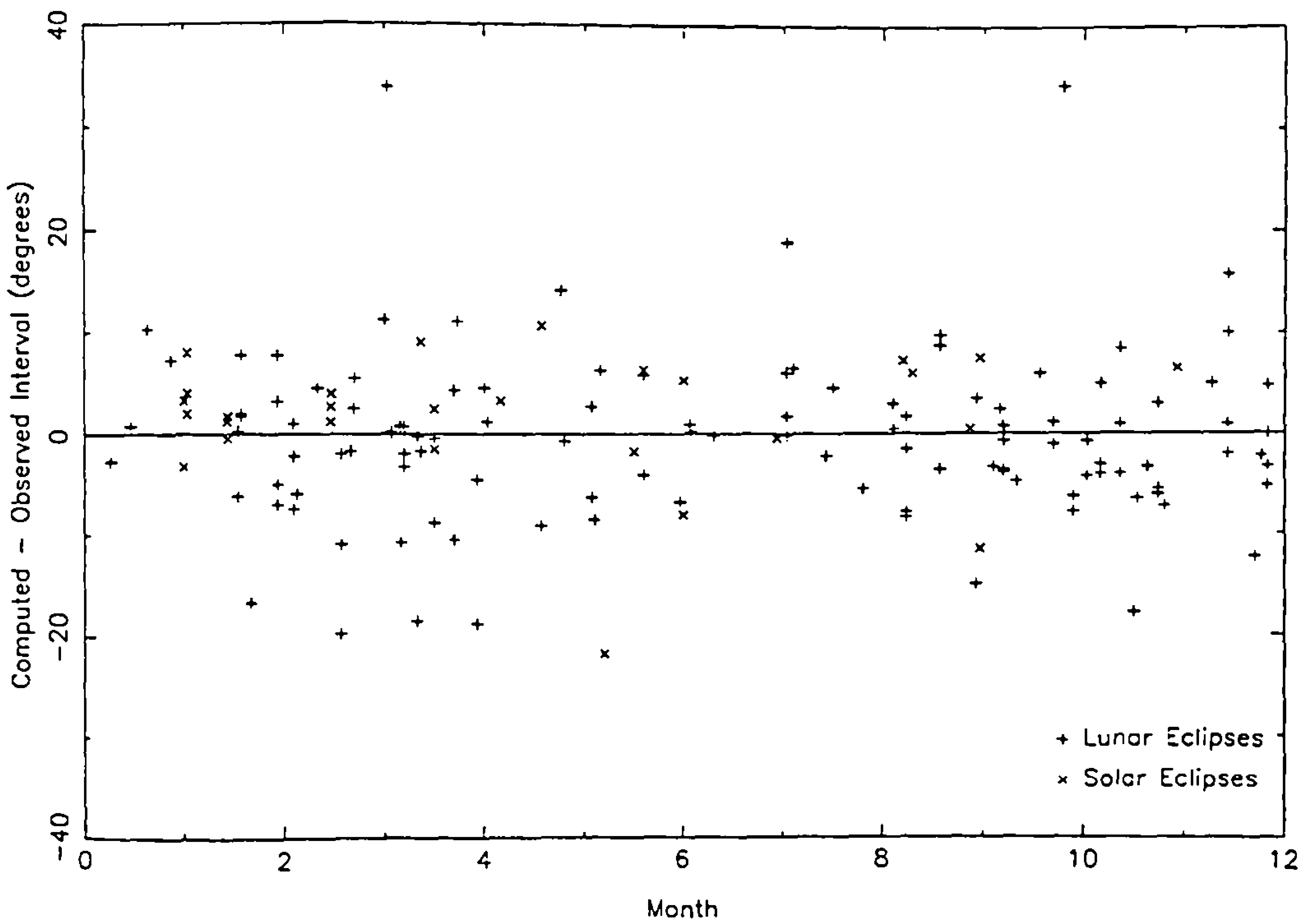


Figure 2.4: The error in the observed solar and lunar eclipse timings over the seasons.

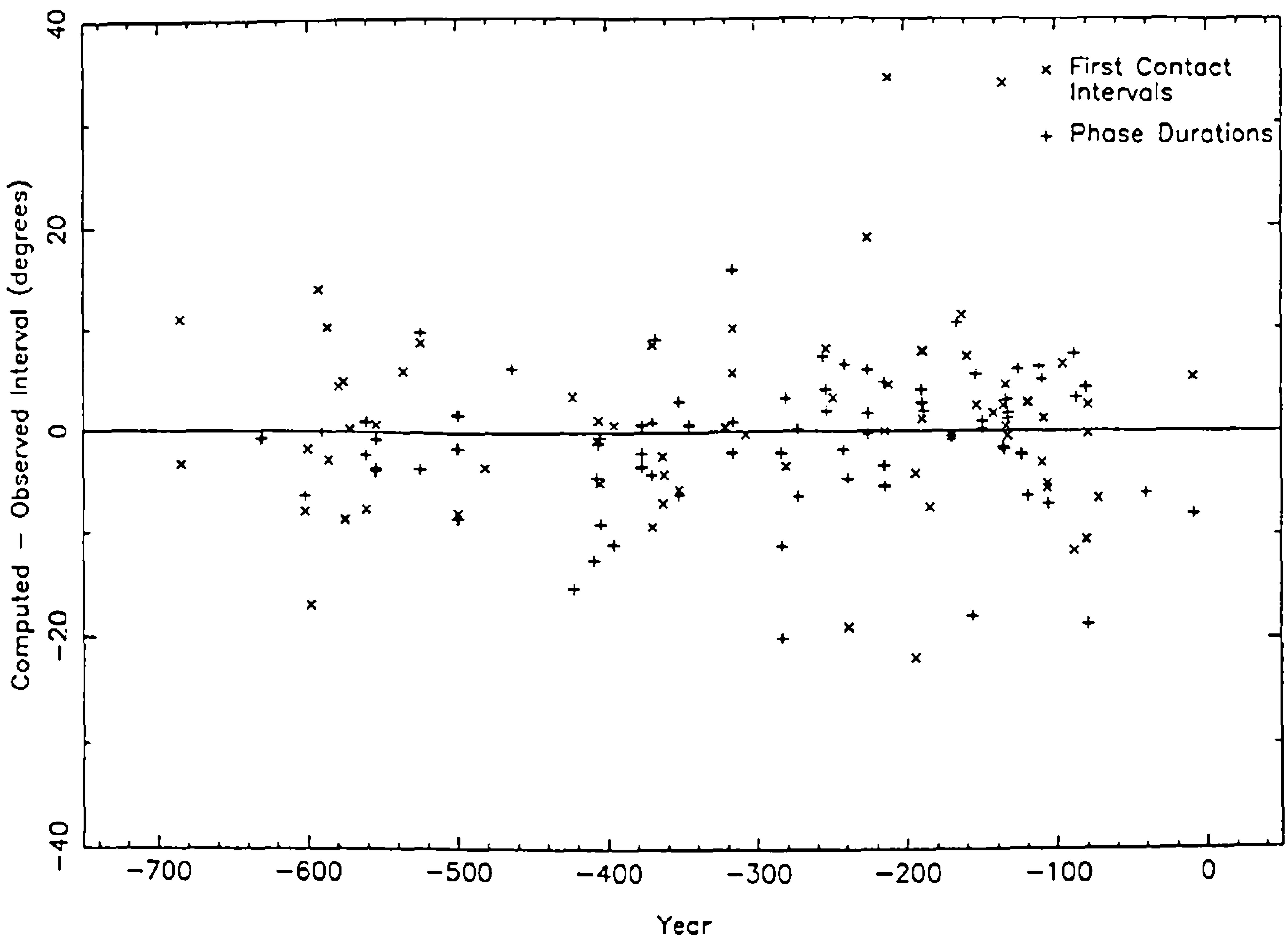


Figure 2.5: The error in the observed first contact intervals and phase durations.

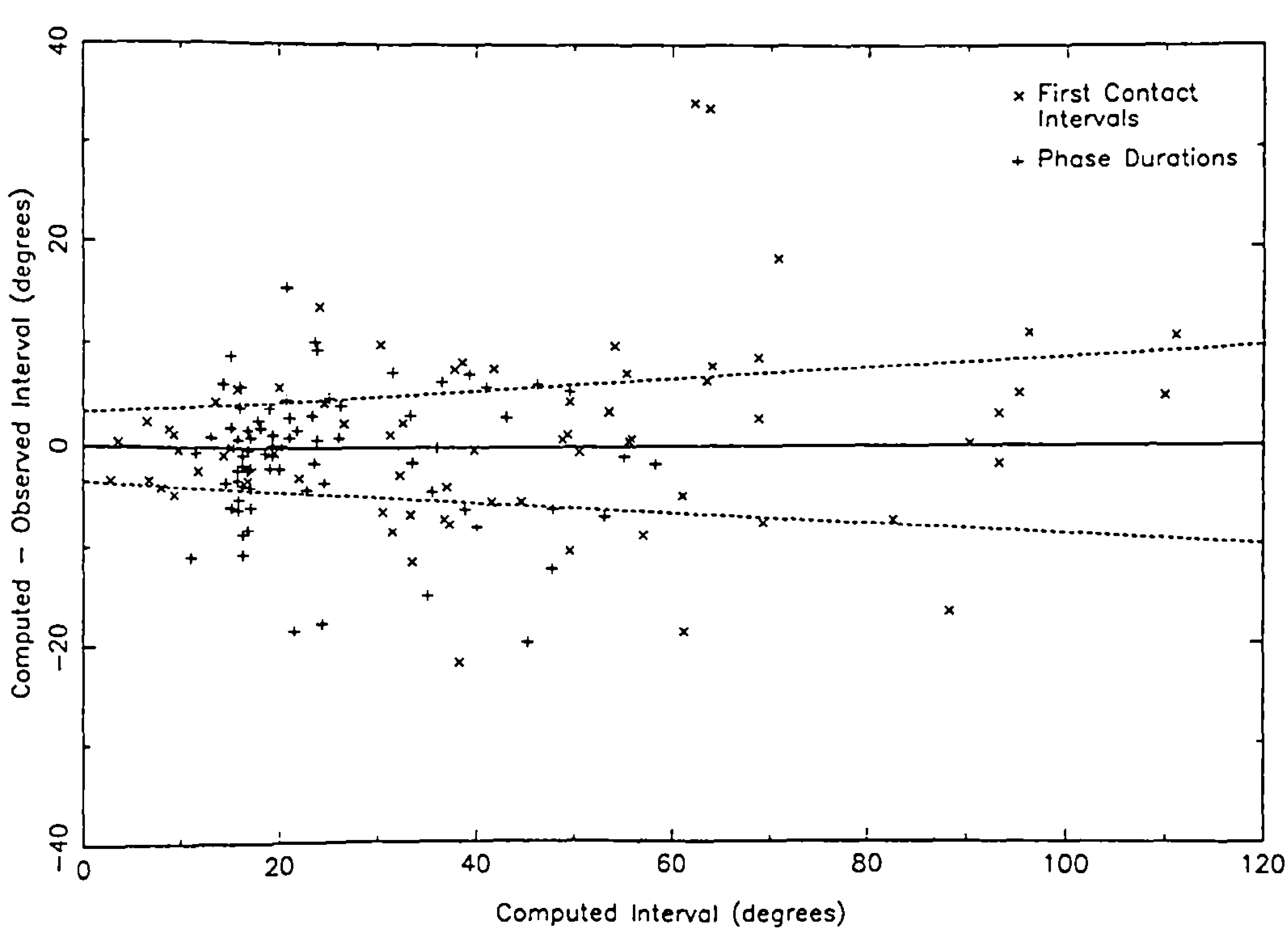


Figure 2.6: The error in the observed first contact intervals and phase durations plotted against the computed interval.

time of first contact relative to sunrise or sunset as they did for the durations of the various phases of the eclipses, and that the same clocks were used for their observations of both lunar and solar eclipses. There was no noticeable improvement in the accuracy of these clocks over the whole of the Late Babylonian period, despite an improvement in the precision with which the Babylonians quoted their times in the middle of the sixth century BC. These clocks were subject to both random errors in drift arising from the fact that they could only be rated to an accuracy of about $8\frac{1}{2}$%, and could only be read with an accuracy of about 3° (12 minutes). Thus a typical Babylonian eclipse timing of about 40° (2 hours 40 minutes) has an accuracy of just under 7° (24 minutes).

2.7 Accuracy of the Predicted Times

In addition to the hundred or so timed eclipse observations recorded in Late Babylonian history, there are about as many timed predictions. The majority of these relate to events that could not be observed in Babylon, for if the eclipse was seen then the observation was recorded in Astronomical Diaries; only those recorded in the Almanacs and Normal Star Almanacs refer to eclipses that may have actually been seen by the Babylonian astronomers. In analysing these records, therefore, I am really trying to evaluate the Babylonian methods of making eclipse predictions largely from their failures. However, there is no reason to suppose that the Babylonian schemes would be less reliable when they predicted an eclipse when the event was not visible than when it was seen. I shall begin by considering the records of timed lunar eclipse predictions.

Table 2.6 lists all of the lunar eclipse predictions contained in the dated Late Babylonian Astronomical Texts for which a time is fully preserved. The records may be divided into three categories: umbral lunar eclipses that were visible somewhere on the Earth's surface but not necessarily at the longitude of Babylon (A), penumbral lunar eclipses (B), and failed predictions (F). Only the first category can be considered as being "successful" in the context of Babylonian astronomy. There are no firmly dated records of Babylonian observations of penumbral eclipses and these are difficult to observe in any case, and so the category B predictions can perhaps be thought of as "near-misses". Of the 48 eclipses listed in Table 2.6, 30 are in category A, 16 in B, and 2 in F. Thus, in this sample, the Babylonian predictions of lunar eclipses were successful about 63% of the time, with a further 33% being near-misses. Only 4% of the time did their predictions completely fail.

For the category A predictions, Table 2.6 gives both the local time of the eclipse as predicted by the Babylonian astronomers, and that deduced from modern computations. In making these computations, I have assumed that the predicted times relate to the expected time of first contact. The errors in the predicted times are shown in Figure 2.7. The mean error in the predicted times, about -0.40 hours, is shown by the dashed line in the Figure. This is sufficiently close to zero to confirm that the predicted times do indeed relate to the moment when the eclipses were expected to start. If the predicted times related to the end of the eclipse, then the mean error would be increased by about 3 hours, the average duration of the eclipses. If it were the middle of the eclipse that was intended, then the mean error would still be increased by about $1\frac{1}{2}$ hours.

The average accuracy of the category A eclipses is about 1.32 hours. There is no evidence for any improvement in the accuracy of these predictions down the centuries, mirroring the result found for the observed timings. This suggests that the same methods of making the predictions were used for the early predictions as for the later ones. I shall discuss the implications of this result in Section 2.8 below.

Returning to the category B predictions in Table 2.6, the predicted and computed local times have once more been given. However, these predictions relate to penumbral eclipses, and these events only have virtual contacts. Therefore, the computed time relates to the moment when the Moon made its closest approach to the Earth's umbral shadow. The error in the predicted times are shown in Figure 2.8. Unsurprisingly, there is a much greater scatter in these times than there was for the category A

Date	Description	Category	Predicted LT (h)	Computed LT (h)
-730 Apr 9	Omitted at 60° after sunrise	A	9.72	11.72
-667 May 2	Omitted at 40° after sunrise	A	8.04	9.33
-667 Oct 25	Omitted at 30° before sunset	A	15.64	14.90
-649 May 13	Omitted at 60° before sunset	A	14.86	16.75
-590 Sep 15	Omitted with sunrise	A	5.68	6.02
-572 Sep 25	Omitted at 35° before sunset	A	15.80	13.77
-525 Mar 24	... at 25° before sunset	A	16.35	13.80
-414 Mar 26	Omitted at 12° before sunset	A	17.28	13.47
-409 Jun 28	... at 70° after sunrise	A	9.50	9.72
-408 Nov 11	Omitted at 80° after sunrise	B	11.80	4.14
-395 Mar 26	Omitted at 10° before sunset	A	17.41	13.12
-379 Oct 22	... at 20° after sunrise	F	9.67	-
-378 Oct 11	Omitted at 12° after sunrise	B	6.95	9.36
-356 Feb 14	Omitted at 40° before sunset	B	14.77	14.91
-334 Dec 3	Omitted at 60° before sunset	A	13.09	12.36
-291 Aug 11	Omitted at 27° after sunrise	B	6.97	6.43
-278 Jun 19	... at 18° before sunset	A	17.95	18.19
-278 Nov 15	Omitted at 45° after sunset	F	20.29	-
-248 Apr 19	Omitted at 39° before sunset	B	15.89	9.11
-248 Oct 13	Omitted at 30° after sunset	B	19.78	21.93
-246 Sep 22	Omitted at 16° after sunrise	A	6.91	7.29
-232 Dec 14	Omitted at 74° after sunrise	A	11.91	10.67
-225 Feb 6	Omitted at 30° before sunset	A	15.34	12.65
-214 Jan 5	... at 58° after sunrise	A	10.54	9.88
-194 Jun 20	Omitted at 15° before sunset	B	18.15	18.99
-194 Nov 16	Omitted at 45° after sunset	B	20.26	23.83
-193 May 11	Omitted at 94° after sunrise	A	11.46	10.98
-191 Apr 19	... at 2° after sunset	A	18.63	17.91
-172 Mar 21	Omitted at 47° after sunrise	B	9.11	7.81
-169 Feb 16	Omitted at 31° before sunset	A	15.42	14.41
-169 Aug 13	Not seen at 4° before sunrise	A	4.94	5.60
-168 Jan 7	Omitted at 7° before sunrise	B	6.49	3.24
-162 Sep 23	Omitted at 48° after sunrise	A	9.07	9.04
-161 Feb 18	Omitted at 31° before sunset	B	15.45	8.39
-161 Aug 14	Omitted at 25° before sunset	B	17.10	17.11
-160 Feb 7	Omitted at 10° after sunrise	A	7.32	10.16
-158 Jul 12	Omitted at 58° after sunrise	B	8.75	8.09
-140 Jul 22	Omitted at 34° before sunset	A	16.76	14.43
-140 Dec 17	Omitted at 78° after sunset	B	22.20	1.94
-136 Oct 5	Omitted at 79° before sunrise	B	0.81	2.77
-133 Sep 3	... at 30° after sunset	A	20.46	20.48
-132 Jan 29	Omitted at 92° before sunrise	B	0.62	6.51
-131 Jan 17	... at 60° after sunset	A	21.12	20.55
-106 Mar 11	Omitted at 62° after sunrise	A	10.27	9.73
-86 Aug 24	Omitted at 30° after sunrise	A	7.34	10.52
-76 Feb 9	Omitted at 76° after sunrise	A	11.68	11.77
-75 Jul 24	... at 8° before sunrise	A	4.47	5.17
-62 May 3	... at 9° after sunrise	A	5.89	4.49

Table 2.6: Timed lunar eclipse predictions.

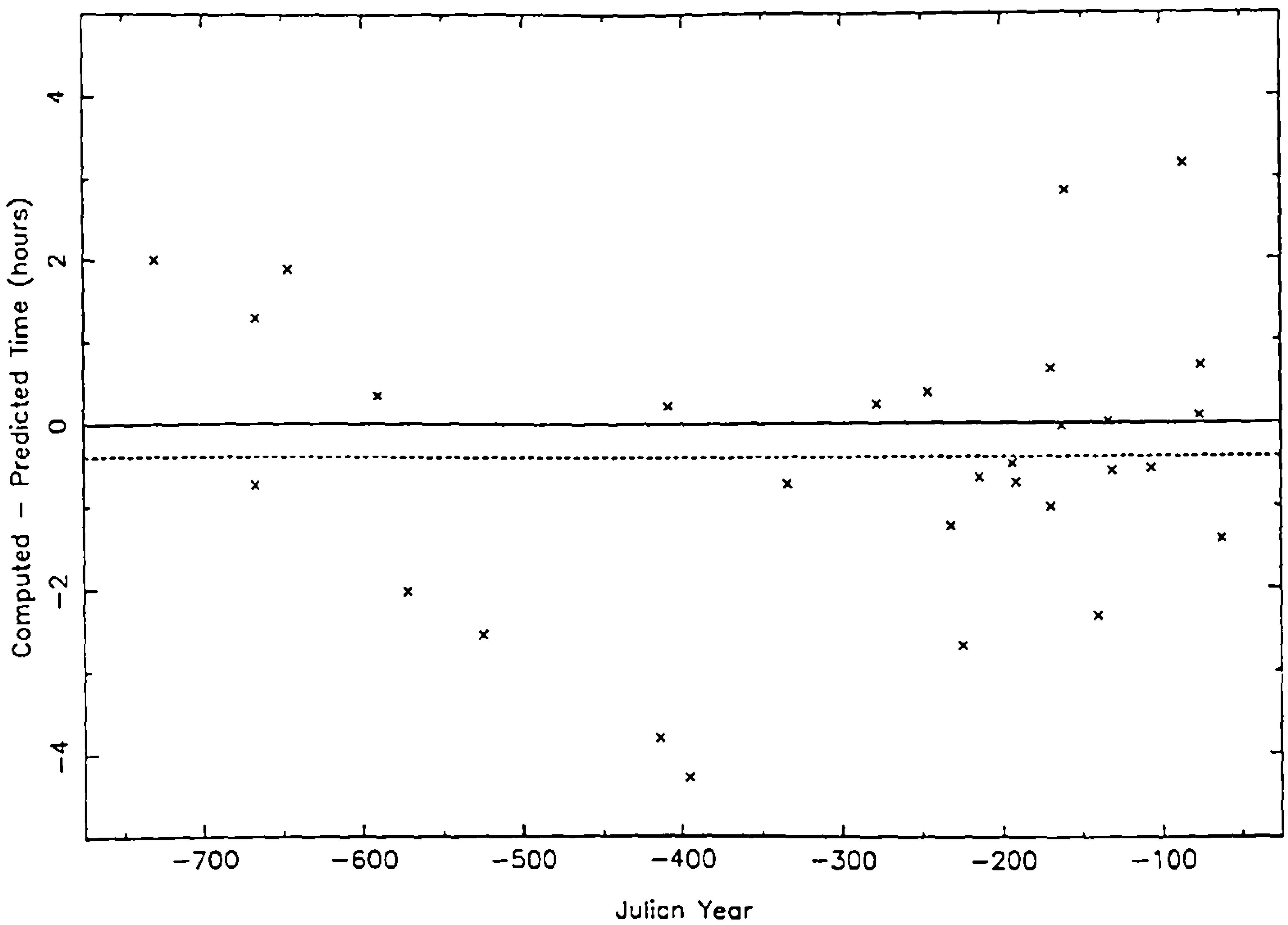


Figure 2.7: The error in the predicted time of the category A lunar eclipses over the Late Babylonian period.

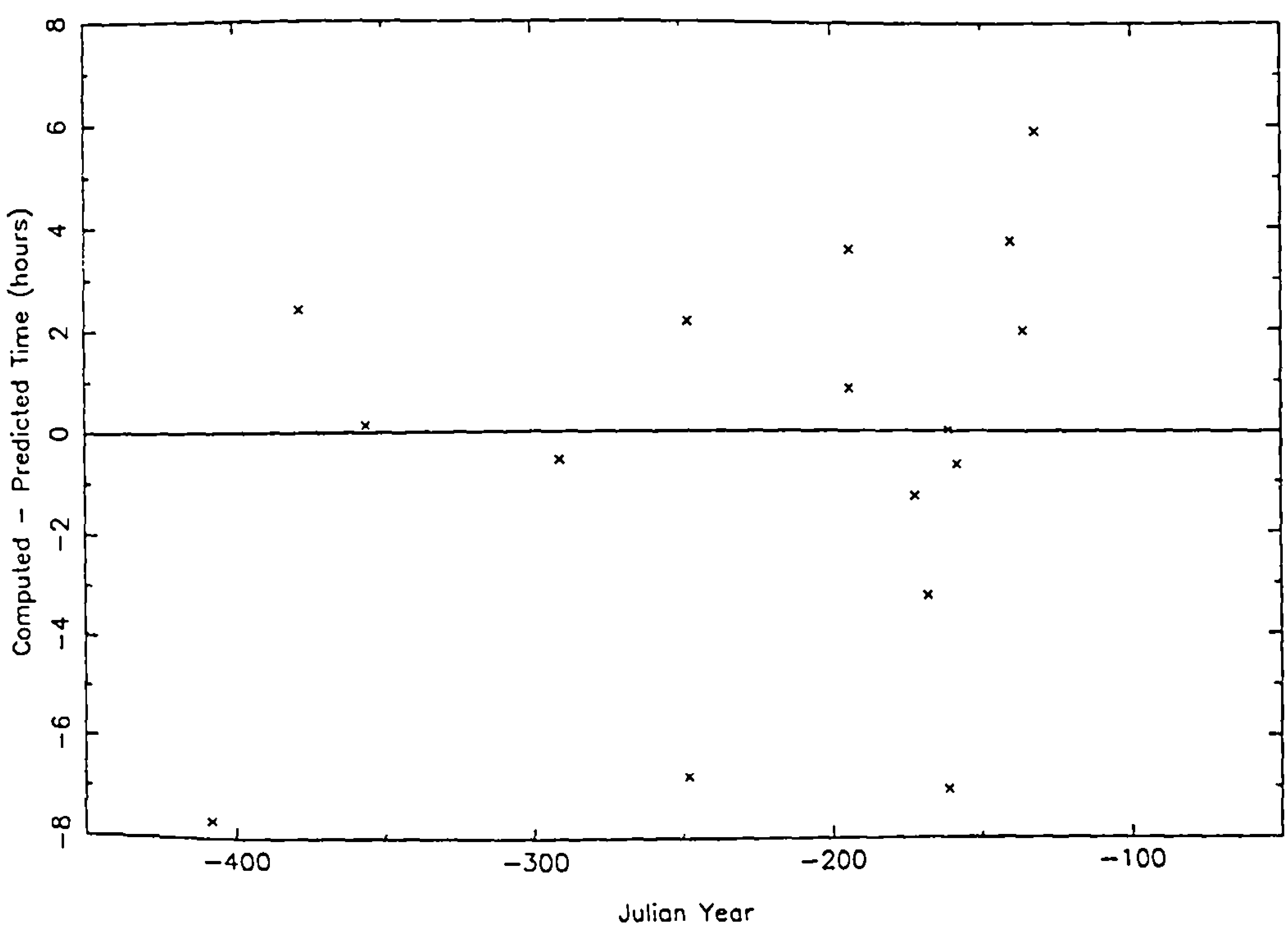


Figure 2.8: The error in the predicted time of the category B lunar eclipses over the Late Babylonian period.

predictions. The mean accuracy of these times is about 3.00 hours, more than twice as poor as that of the category A predictions.

Moving on now to the timed solar eclipse predictions, there are 66 records preserved in Late Babylonian history that give a fully preserved time when the eclipse was expected to occur. These are listed in Table 2.7. As with the lunar predictions, it is possible to divide the solar eclipses in Table 2.7 into different categories: solar eclipses that were visible at Babylon, or would have been visible there if the Sun was above the horizon at the time of the eclipse (i.e., the eclipse was visible at the latitude but not necessarily the longitude of Babylon) (A), and eclipses that would not be visible at Babylon under any circumstances (i.e., the eclipse passed either completely to the north or to the south of Babylon) (B). Of the 66 predictions in this sample, 28 (42%) fall into category A, and 38 (58%) into B.

Considering first the category A predictions of solar eclipses, both the predicted and the computed local times are given in Table 2.7. The computed times have once more been determined assuming that the prediction relates to the moment of first contact. The error in the predicted times are shown in Figure 2.9. Once more, the mean error of the prediction is shown by the dashed line in the Figure. This mean error is equal to about +0.23 hours, which is very close to zero and provides yet more proof that the predicted times indeed relate to first contact. The mean accuracy of these predictions is about 2.06 hours.

For the category B predictions, the computed times relate to the moment when the path of the eclipse makes its closest approach to Babylon. The errors in the predicted times of these eclipses are shown in Figure 2.10. Clearly there is a very great scatter in the errors of these times, ranging from close to zero to over 9 hours. The mean accuracy of the category B predictions is about 3.59 hours.

In both categories of the solar eclipse predictions there does not appear to be any change in the accuracy of the times down the centuries. This was also found for the lunar eclipse predictions. Furthermore, there is no evidence for any difference in the accuracy of the predicted times given in the Almanacs and Normal Star Almanacs, and those given in the Diaries, Goal-Year Texts and Eclipse Texts. This suggest that all of the eclipse times were predicted in advance, and then if the eclipse was not observed, the predicted time was placed in the Diary. Certainly, predictions accurate to a couple of hours would have at least given the Babylonian astronomers a rough idea of when to watch for an eclipse.

Finally, let me discuss the small number of lunar eclipses that were observed to rise eclipsed, and for which an estimate of the time that the eclipse started are given. These are listed in Table 2.8. The errors in the predicted first contact times are shown in Figure 2.11. The mean accuracy of these times is about 0.62 hours. This is significantly better than the accuracy of the purely predicted lunar eclipses discussed above, suggesting that these times were not predicted using the same scheme. It seems more likely that the times were instead estimated from the observed later phases of the eclipses.

2.8 Methods of Eclipse Prediction

As soon as the Babylonian astronomers began keeping systematic records of their observations in the Astronomical Diaries, it seems that they also began to make predictions of celestial events. Most importantly, as far as this present study is concerned, they began to predict lunar, and probably solar, eclipses. Unfortunately, descriptions of the procedures that they used to make these early predictions are not preserved. However, it is possible to deduce these methods, or at least to deduce plausible methods that the Babylonian astronomers could have used, from the records of the predictions themselves. As there are far fewer solar than lunar eclipse predictions recorded in the Late Babylonian Astronomical Texts, and more particularly in the Eclipse Texts, the following discussion will focus mainly on lunar eclipses.

The earliest scheme for predicting eclipses that was recognized by the Babylonian astronomers was the simple rule-of-thumb that eclipses can recur after six months, a multiple of six months, or

Date	Description	Category	Predicted LT (h)	Computed LT (h)
-473 Nov 25	... at 40° after sunrise	B	9.47	16.42
-472 May 20	... at 30° before sunrise	B	3.09	3.06
-471 May 9	... at 70° before sunset	B	14.09	16.96
-458 Aug 12	... at 40° after sunset	B	16.15	22.99
-455 Aug 2	... at 50° before sunset	A	15.62	11.37
-357 Sep 5	Omitted at 50° before sunrise	A	2.21	0.64
-355 Feb 18	Omitted at 46° before sunrise	A	5.73	3.53
-332 Oct 27	Omitted at 30° after sunrise	B	8.43	7.77
-330 Oct 5	Omitted at 1° after sunset	A	18.01	22.86
-302 Sep 25	Omitted at 78° after sunset	B	23.30	0.52
-291 Aug 25	Not seen at 25° before sunset	A	16.94	19.61
-266 Oct 17	... at 57° before sunset	B	13.93	18.00
-255 Mar 24	Pass by at 5° after sunset	B	18.40	1.05
-246 Sep 7	Not seen at 74° after sunrise	B	14.21	10.88
-241 Jun 15	To be watched for at 51° before sunset	A	15.74	11.12
-232 Nov 30	Not seen at 44° after sunrise	B	9.82	0.02
-230 May 15	Omitted at 5° after sunset	A	19.19	20.57
-229 May 5	To be watched for at 54° after sunrise	A	8.88	8.90
-228 Mar 25	Omitted at 28° after sunset	B	19.96	3.27
-226 Mar 3	... at 10° after sunrise	B	6.96	6.50
-225 Jul 17	Omitted at 73° before sunset	B	14.21	11.13
-218 Apr 3	... at 87° after sunset	B	0.03	17.73
-211 May 15	Not seen at 35° before sunset	A	16.54	19.96
-209 Sep 18	Not seen at sunset	A	18.22	19.64
-206 Jan 22	Pass by at 58° after sunset	B	21.03	6.63
-206 Jul 17	Pass by at 49° after sunset	A	22.35	19.44
-205 Jan 11	Pass by at 20° after sunset	A	18.39	22.32
-204 Jun 25	To be watched for at 87° before sunset	B	13.36	18.12
-200 Apr 13	Omitted at 58° before sunrise	B	1.73	23.10
-199 Mar 4	To be watched for at 45° before sunset	B	14.74	13.03
-194 Nov 29	Omitted at 91° after sunset	A	23.19	0.56
-193 May 26	Omitted at 77° after sunset	A	0.12	0.24
-189 Sep 7	Not seen at 28° before sunset	B	16.53	18.24
-188 Feb 2	Omitted at 78° before sunset	B	12.08	18.44
-183 May 6	To be watched for at 8° after sunrise	B	5.78	3.71
-168 Jan 22	Omitted at 93° after sunset	A	23.36	21.90
-164 Oct 29	Omitted at 64° after sunset	B	21.78	22.75
-162 Sep 8	Omitted at 30° before sunrise	B	3.61	20.74
-161 Mar 5	Not seen at 30° after sunrise	B	8.25	9.17
-161 Aug 28	Omitted at 16° after sunset	B	19.63	20.92
-154 Oct 10	To be watched for at 35° after sunrise	A	8.49	3.76
-144 Sep 19	Not seen at 59° after sunrise	B	9.74	9.48
-143 Sep 8	Omitted at 39° before sunrise	A	3.02	1.74
-140 Dec 31	Omitted at 87° before sunrise	A	1.19	1.12
-136 Oct 20	Not seen at 81° before sunset	B	12.14	14.47
-132 Aug 7	Pass by at 9° after sunset	B	19.45	23.43
-131 Feb 1	Omitted at 21° after sunset	B	18.69	15.14
-128 Nov 20	... at 45° before sunset	A	14.20	16.25
-127 Apr 16	... at 7° after sunset	B	18.93	20.40
-124 Sep 7	Not seen at 60° before sunset	A	14.38	18.25
-119 Nov 11	To be watched for at 79° before sunset	A	12.05	13.50
-118 May 7	Omitted at 13° before sunrise	B	4.36	2.85
-118 Oct 31	Omitted at 44° after sunset	A	20.42	22.72
-116 Mar 16	Pass by at 54° after sunset	B	21.56	1.23
-107 Apr 6	Omitted at 81° before sunrise	B	0.30	9.18
-102 Jul 8	To be watched for at 30° before sunset	A	17.13	18.42
-86 Feb 14	Omitted at 76° before sunrise	A	1.46	23.24
-84 Jan 23	Not seen at 63° after sunrise	B	11.02	14.38
-79 Sep 20	Not seen at 10° after sunrise	B	6.50	7.12
-77 Mar 6	To be watched for at 75° after sunrise	A	11.22	11.30
-62 May 18	Not seen at 30° after sunrise	A	7.09	6.80
-40 Feb 15	Not seen at 57° before sunset	B	21.28	18.01
-11 Jul 21	To be watched for at 50° before sunset	B	15.70	12.98
-6 Apr 29	To be watched for at 47.5° before sunset	A	15.50	16.00
-6 Oct 22	To be watched for at sunrise	A	6.37	7.76
+37 Jan 5	To be watched for at 75° before sunset	B	12.04	9.28

Table 2.7: Timed Solar eclipse predictions.

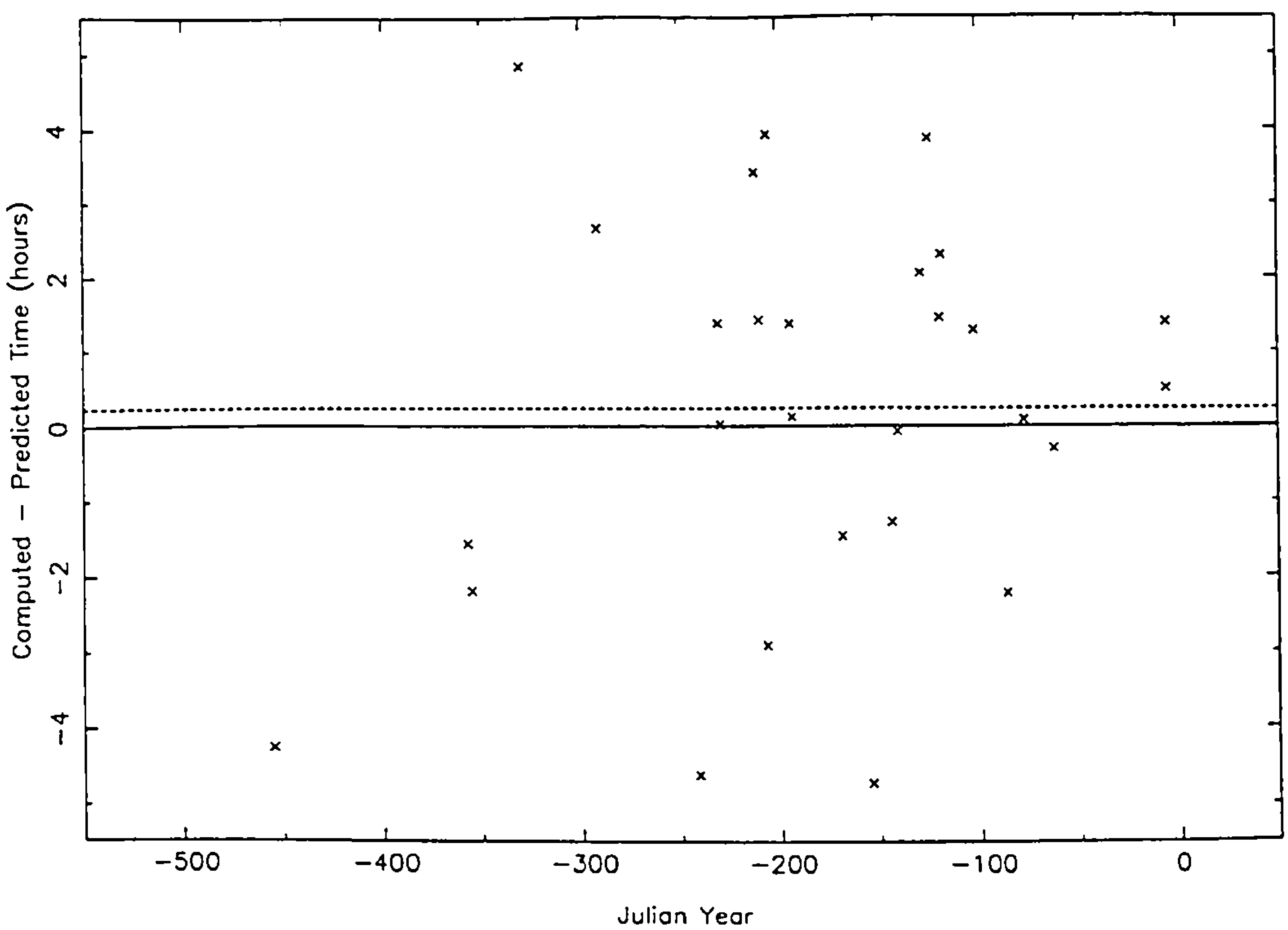


Figure 2.9: The error in the predicted time of the category A solar eclipses over the Late Babylonian period.

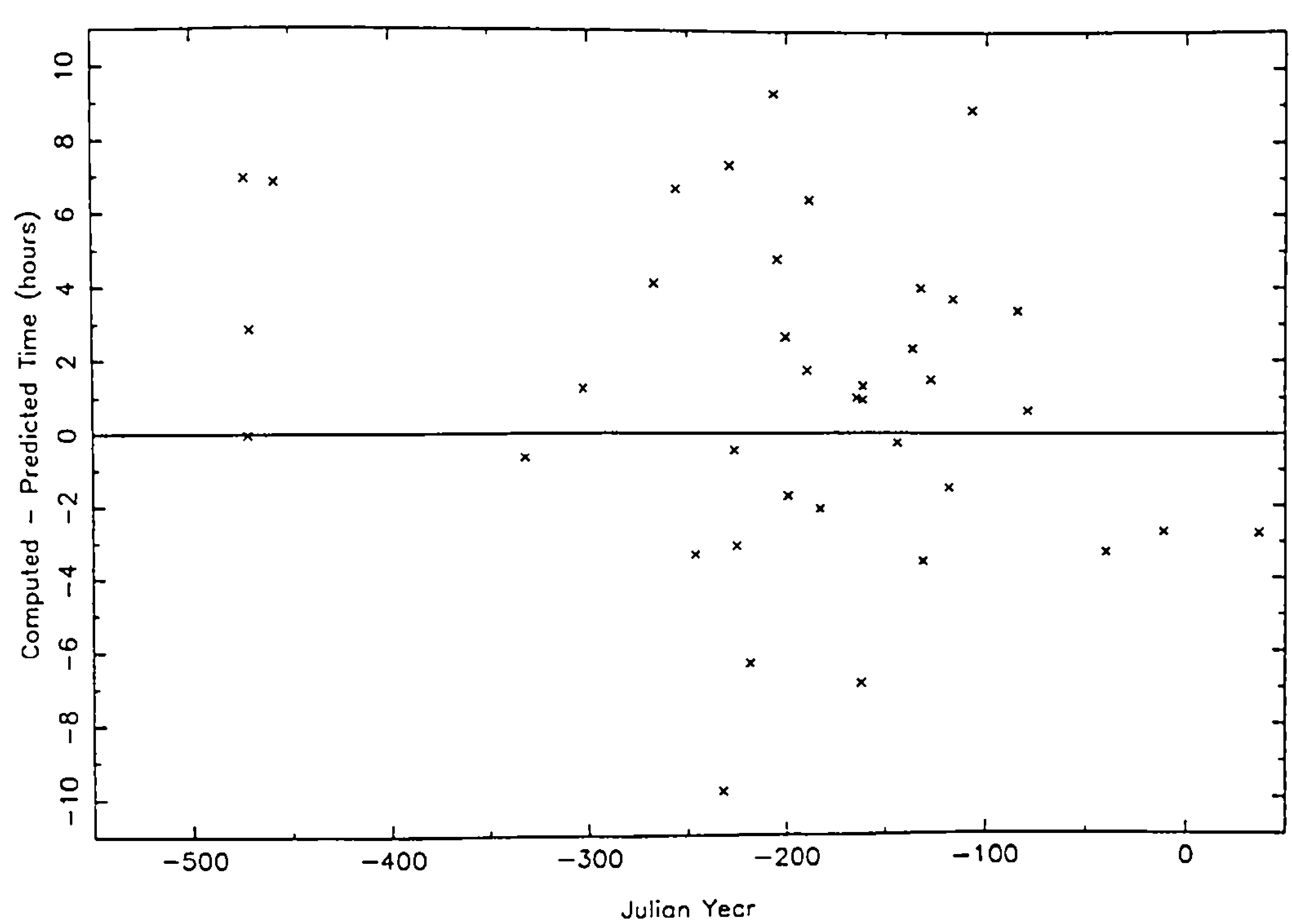


Figure 2.10: The error in the predicted time of the category B solar eclipses over the Late Babylonian period.

Date	Description	Predicted LT (h)	Computed LT (h)
-590 Mar 22	At 30° before sunset	15.98	16.29
-562 Sep 5	At 35° before sunset	16.13	17.14
-189 Aug 23	At 30° before sunset	16.63	15.68
-170 Aug 23	At 42° before sunset	15.83	15.91
-135 Sep 24	At 30° before sunset	16.09	16.78
-66 Jan 19	At 16° before sunset	16.07	15.07
-65 Jan 8	At 30° before sunset	15.04	14.35
-65 Dec 28	At 6° before sunset	16.60	16.37

Table 2.8: Times of first contact for lunar eclipses which rose eclipsed.

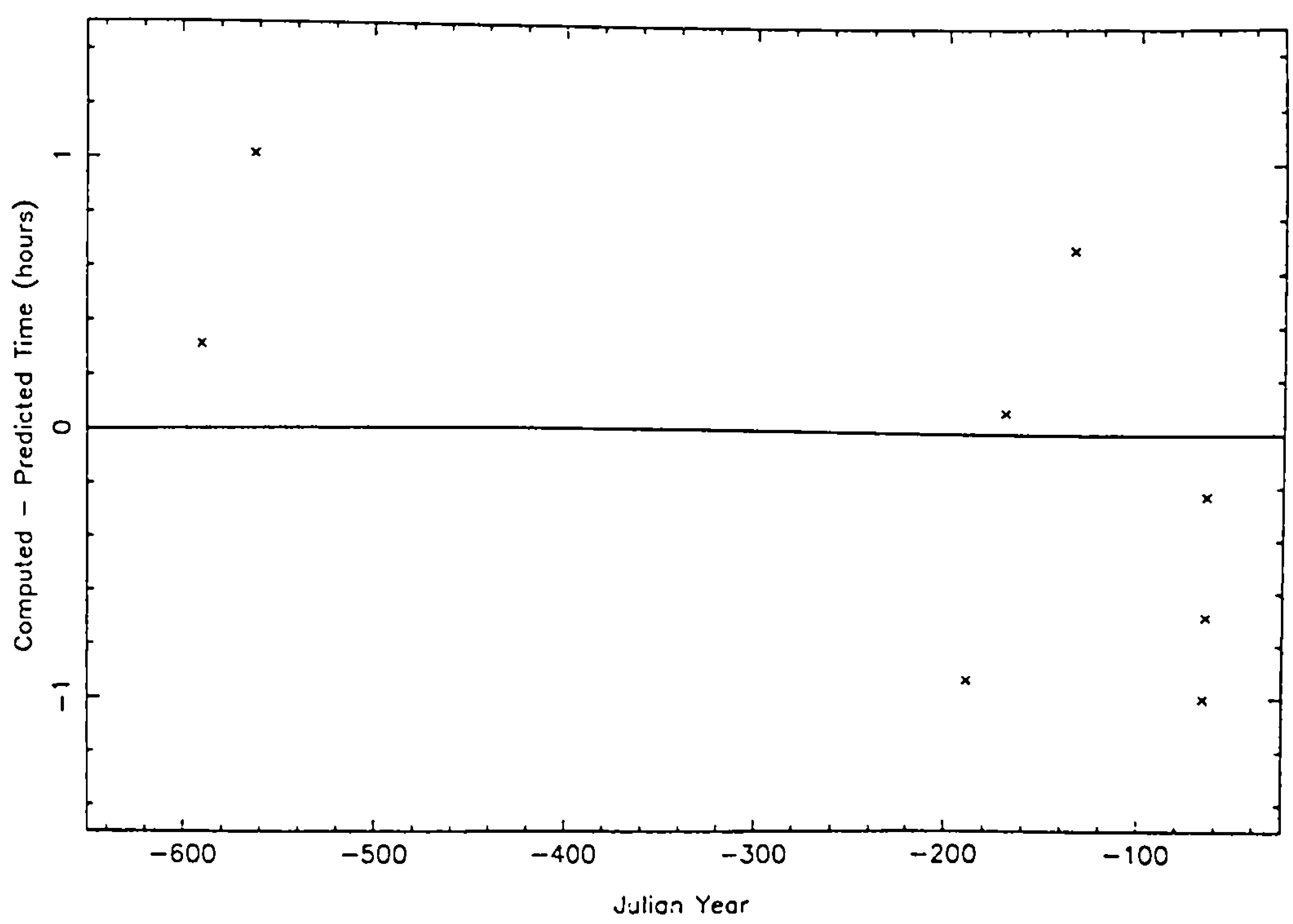


Figure 2.11: The error in the predicted time of first contact for lunar eclipses which rose eclipses over the Late Babylonian period.

a multiple of six months minus one. In other words, an eclipse is possible after six, eleven, twelve, seventeen, eighteen, etc., months after a previous eclipse. From this comes the concept of "eclipse possibilities", which are dates when an eclipse is possible but not necessarily seen. These therefore occur five or more generally six months after the previous eclipse possibility. The next step was to formulate a method by which the gaps of five and six months between eclipse possibilities were to be arranged. Britton (1989) has shown that by a basic analysis of the observational record, simple schemes for these arrangements could easily be identified. The most important of these contains 38 eclipse possibilities within 223 synodic months, a period which has become known as the "Saros".[35] After this period, the arrangement of the eclipse possibilities would begin again.

As discussed in Section 1.3 above, the Saros period of 223 synodic months is remarkable because it is also approximately equal to 242 draconitic months, 239 anomalistic months, and 241 sidereal months. This means that eclipses of similar entrance angle, magnitude and duration recur after one Saros, making it very useful for predicting eclipses. The Saros was identified by the Babylonian astronomers by at least the sixth century BC (Beaulieu & Britton 1994), and probably much earlier (Parpola 1983). It played an important role in the Babylonian lunar theory from its discovery down to the mathematical astronomy of the Seleucid period (Neugebauer 1975).

Within a Saros period of 223 synodic months, there are 38 eclipse possibilities: 33 of which were separated by six month intervals, and the remaining 5 by five month intervals. As Britton (1989) has shown, it is easy to demonstrate from the observational record that the eclipse possibilities separated by five months should be arranged so that they split up those separated by six months into groups of seven or eight eclipse possibilities. In other words, if the first eclipse of the 38 eclipses in a Saros period comes five months after the preceeding eclipse possibility, then it will be followed by seven eclipses (nos. 2–8) each of which is six months after the preceeding eclipse, then an eclipse (no. 9) at five months, six (nos. 10–15) at six months, another (no. 16) at five months, seven (nos. 17–23) at six months, another (no. 24) at five months, six at six months (nos. 25–30), one more (no. 31) at five months, and then finally seven (nos. 32–38) at six month intervals. Thus, the 38 eclipse possibilities are divided into five groups, each of which begins with an eclipse possibility five months after the preceeding eclipse, containing eight, seven, eight, seven, and eight eclipses respectively. This is often written as 8–7–8–7–8.[36]

The next problem faced by the Babylonian astronomers was to decide where to begin the scheme they had derived for distributing the eclipse possibilities within the Saros period. Their solution can be immediately seen from the tablets LBAT *1414, LBAT 1415 + 1417 + 1417, and LBAT *1419. As mentioned in Section 2.5 above, Walker (1997) has suggested that these three tablets formed part of a series of eclipses stretching from 747 BC to 315 BC, and that running throughout them is the expected 8–7–8–7–8 grouping of eclipse observations, beginning with the eclipse on the 6th February 747 BC. A reconstruction of this scheme is shown in columns 1–24 of Table 2.9. In this Table, eclipses which were (at least partly) visible in Babylon are indicated in bold. There is no distinction between eclipses not visible in Babylon because they occurred during the day, and those not visible because there was no umbral eclipse.[37] Supplementing the eclipse records from LBAT *1414, LBAT 1415 + 1417 + 1417, and LBAT *1419, with those from the Diaries and other NMAT texts, dates on which the Babylonian astronomers either observed or predicted an eclipse are underlined in the Table.

Interestingly, there are no eclipse records between 747 BC to 315 BC that contradict the scheme presented in this Table. Indeed, between 747 BC and 341 BC the scheme correctly predicts every eclipse that was visible in Babylon. On the 29th September 340 BC, and again on the 10th October 322 BC, a lunar eclipse occurred which was not predicted by this scheme. However, these two eclipses

[35] The Babylonians simply called this period "18-years".

[36] Of course, the definition of the beginning of the Saros period is arbitrary, and the distribution could equally well be 7–8–7–8–8, 8–7–8–8–7, 7–8–8–7–8 or 8–8–7–8–7.

[37] As noted in Section 2.5 above, there is no firm evidence that the Babylonian astronomers observed any penumbral eclipses.

both had very small magnitudes (0.10 and 0.13 respectively), and may not have been noticed by the Babylonian astronomers.[38] It would therefore seem that this scheme was used throughout the period from 747 BC to 315 BC. Furthermore, extending the scheme for a further three Saros periods down to at least 279 BC, there is still no disagreement between this scheme and the records of observed and predicted eclipses on the NMAT. This suggests that it was used at least until 279 BC.

There are two other small groups of tablets which give information on the eclipse schemes of this period: LBAT *1418, which has been published by Sachs & Hunger (1998); and LBAT 1428, which has become known as the "Saros Canon", and two related texts, LBAT *1422 + *1423 + *1424 and LBAT *1425, which have been published by Aaboe et al. (1991). Both of these groups of texts contain calculations, in the latter group made during the Seleucid Period, for earlier eclipses. LBAT *1418, which contains dates of eclipses from parts of the years between 647 BC and 574 BC, is based upon the same scheme as given in columns 1–27 of Table 2.9. The other group of texts, however, contain a variant scheme that gives arise to eclipse possibilities on different dates. According to Aaboe et al. (1991) this scheme in the Saros Canon and related texts probably originally covered the period from 527 BC to 257 BC. This prompted Britton (1993) to suggest that the date of 527 BC marked a reform of the scheme used in LBAT *1414 etc. to the scheme, which he called the "New Saros", found in the Saros Canon. However, when the dates of the eclipse possibilities given by this "New Saros" are compared with the actual historical record as shown in Table 2.9, it is clear that they do not match up. Instead, the scheme on LBAT *1414 etc. continues down until at least 279 BC.

Sometime between 279 BC and 249 BC, there was indeed a reform of the Saros. This is shown by the eclipse prediction on the 19th April 248 BC. This record states that this eclipse possibility occurred five months after the preceeding eclipse possibility. This contradicts the scheme on LBAT *1414 etc., but does in fact fit the New Saros recorded on the Saros Canon. Therefore, sometime between the 13th November 279 BC, which is the last eclipse possibility predicted by the LBAT *1414 etc. scheme but not predicted by the New Saros, and 19th April 248 BC, which is the first eclipse predicted by the New Saros but not by the scheme on LBAT *1414 etc., the distribution of eclipse possibilities was reformed. In Table 2.9 I have arbitrarily marked this, by a vertical line, between columns 27 and 28. However, given the likelihood that the Saros Canon contained eclipse possibilities from 527 BC to 257 BC, I suggest that this latter date may be the true date when the scheme was introduced, and the earlier eclipse possibilities on the Saros Canon are a projection of this scheme into the past, presumably to compare the scheme with the record of observed eclipses.

It would appear that there were two further reforms of the Saros: one around 200 BC, and the other around 115 BC. The former reform came after only three Saros periods, during which time four unpredicted eclipses, albeit eclipses of very small magnitude, were visible in Babylon. Thus I believe that the scheme found on the Saros Canon, which has long been thought of as being the source of many of the eclipse predictions in Babylonian history, was in fact only used for less than sixty years, and even then without great success. The basis for the reform around 115 BC is less clear. The scheme used for the previous five Saros periods accounted for all of the eclipses visible in Babylon over that time, and so the reform may have been caused not by the failure of observed eclipses to be predicted, but rather by a failure of many predicted eclipses to actually be seen.[39]

The method by which the Babylonian astronomers predicted the time of an eclipse is less well understood. From Section 2.8 above, it is clear that they were attempting to predict the time that an eclipse would begin rather than the moment of syzygy. At first sight this may appear to make the Babylonian methods even more difficult to understand, for it is necessary to take into account the varying durations of the predicted eclipses as well as calculation the moment of conjunction. However, it is this very aspect of the Babylonian predictions that provides the first indication as to how they may have been made. Before I discuss this further, however, it is necessary to make a short

[38] Furthermore, both of these eclipses occurred during the autumn months when there is often a significant amount of cloud in the sky at Babylon.

[39] Britton (1993) proposed that his New Saros was introduced during the sixth century BC for similar reasons.

	1	2	3	4	5	6	7	8	9	10	11	12
1	**-746 Feb 6**	-728 Feb 17	**-710 Feb 27**	**-692 Mar 10**	-647 Mar 21	-656 Mar 31	**-638 Apr 11**	**-620 Apr 22**	-602 May 3	-584 May 13	-566 May 25	-548 Jun 4
2	**-746 Aug 2**	-728 Aug 12	**-710 Aug 23**	**-692 Sep 3**	-647 Sep 14	**-656 Sep 24**	**-638 Oct 6**	-620 Oct 16	**-602 Oct 26**	**-584 Nov 7**	**-566 Nov 18**	**-548 Nov 29**
3	**-745 Jan 26**	-727 Feb 5	**-709 Feb 16**	**-691 Feb 27**	-673 Mar 10	**-655 Mar 20**	**-637 Apr 1**	-619 Apr 11	-601 Apr 22	**-583 May 2**	**-565 May 14**	-547 May 24
4	**-745 Jul 22**	**-727 Aug 2**	-709 Aug 13	**-691 Aug 23**	**-673 Sep 4**	-655 Sep 14	**-637 Sep 25**	**-619 Oct 6**	-601 Oct 17	**-583 Oct 27**	**-565 Nov 8**	-547 Nov 18
5	-744 Jan 15	**-726 Jan 25**	**-708 Feb 6**	-690 Feb 16	**-672 Feb 27**	**-654 Mar 10**	-636 Mar 20	**-618 Mar 31**	**-600 Apr 11**	-582 Apr 22	-564 May 2	**-546 May 14**
6	-744 Jul 11	-726 Jul 22	-708 Aug 1	**-690 Aug 12**	-672 Aug 23	-654 Sep 3	**-636 Sep 13**	**-618 Sep 25**	-600 Oct 5	**-582 Oct 16**	**-564 Oct 27**	-546 Nov 7
7	-743 Jan 3	-725 Jan 15	-707 Jan 25	-689 Feb 6	-671 Feb 16	-653 Feb 27	-635 Mar 10	-617 Mar 21	-599 Mar 31	-581 Apr 12	-563 Apr 22	-545 May 3
8	-743 Jun 30	-725 Jul 11	-707 Jul 21	-689 Aug 2	-671 Aug 12	-653 Aug 23	-635 Sep 2	-617 Sep 14	-599 Sep 24	-581 Oct 5	-563 Oct 16	-545 Oct 27
9	**-743 Nov 25**	-725 Dec 6	**-707 Dec 16**	**-689 Dec 28**	-670 Jan 7	**-652 Jan 19**	-634 Jan 29	**-616 Feb 9**	**-598 Feb 20**	-580 Mar 2	**-562 Mar 13**	**-544 Mar 24**
10	**-742 May 20**	**-724 May 31**	-706 Jun 11	-688 Jun 21	**-670 Jul 2**	**-652 Jul 13**	-634 Jul 24	**-616 Aug 3**	**-598 Aug 15**	-580 Aug 25	**-562 Sep 5**	**-544 Sep 16**
11	**-742 Nov 14**	**-724 Nov 25**	-706 Dec 6	**-688 Dec 16**	**-670 Dec 28**	-651 Jan 7	**-633 Jan 18**	**-615 Jan 29**	-597 Feb 9	**-579 Feb 19**	**-561 Mar 3**	-543 Mar 13
12	**-741 May 10**	-723 May 20	**-705 May 31**	**-687 Jun 11**	-669 Jun 22	-651 Jul 2	**-633 Jul 14**	-615 Jul 24	-579 Aug 4	**-579 Aug 15**	-561 Aug 26	-543 Sep 5
13	**-741 Nov 3**	**-723 Nov 14**	-705 Nov 25	**-687 Dec 5**	**-669 Dec 17**	-651 Dec 27	**-632 Jan 7**	**-614 Jan 18**	-596 Jan 29	**-578 Feb 8**	**-560 Feb 20**	-542 Mar 2
14	-740 Apr 28	-722 May 10	-704 May 20	-686 May 31	**-668 Jun 11**	-650 Jun 22	-632 Jul 2	**-614 Jul 14**	-595 Jul 24	-578 Aug 4	**-560 Aug 15**	-542 Aug 26
15	-740 Oct 22	-722 Nov 3	-704 Nov 13	-686 Nov 24	-668 Dec 5	-650 Dec 16	-632 Dec 26	-613 Jan 7	-595 Jan 17	-577 Jan 28	-559 Feb 8	-541 Feb 19
16	**-739 Mar 20**	-721 Mar 31	**-703 Apr 10**	**-685 Apr 22**	-667 May 2	-649 May 13	**-631 May 24**	-613 Jun 4	-595 Jun 14	-577 Jun 25	-559 Jul 9	-541 Jul 17
17	**-739 Sep 12**	-721 Sep 23	**-703 Oct 3**	-685 Oct 15	-667 Oct 25	**-649 Nov 6**	-631 Nov 16	**-613 Nov 27**	**-595 Dec 8**	-577 Dec 19	-559 Dec 29	**-540 Jan 10**
18	-738 Mar 9	**-720 Mar 19**	**-702 Mar 31**	-684 Apr 10	**-666 Apr 21**	**-648 May 2**	-630 May 13	-612 May 23	**-594 Jun 3**	**-576 Jun 14**	-558 Jun 25	-540 Jul 5
19	**-738 Sep 1**	**-720 Sep 12**	-702 Sep 23	**-684 Oct 3**	**-666 Oct 15**	-648 Oct 25	**-630 Nov 5**	**-612 Nov 16**	**-594 Nov 27**	**-576 Dec 8**	-558 Dec 19	**-540 Dec 29**
20	-737 Feb 26	**-719 Mar 9**	**-701 Mar 20**	-683 Mar 30	**-665 Apr 10**	**-647 Apr 21**	-629 May 2	-611 May 12	**-593 May 23**	**-575 Jun 3**	-557 Jun 14	**-539 Jun 24**
21	-737 Aug 22	**-719 Sep 1**	**-701 Sep 13**	-683 Sep 23	**-665 Oct 4**	**-647 Oct 15**	-629 Oct 26	**-611 Nov 5**	-593 Nov 17	**-575 Nov 27**	**-557 Dec 9**	-539 Dec 19
22	-736 Feb 15	-718 Feb 26	-700 Mar 8	-682 Mar 19	-664 Mar 29	-646 Apr 10	-628 Apr 20	-610 May 1	-592 May 12	-574 May 23	-556 Jun 2	**-538 Jun 13**
23	-736 Aug 11	-718 Aug 22	-700 Sep 1	-682 Sep 13	-664 Sep 23	-646 Oct 4	-628 Oct 15	-610 Oct 26	-592 Nov 5	-574 Nov 17	-556 Nov 27	-538 Dec 8
24	-735 Jan 5	**-717 Jan 16**	**-699 Jan 27**	-681 Feb 7	**-663 Feb 17**	**-645 Mar 1**	-627 Mar 11	**-609 Mar 22**	**-591 Apr 2**	-573 Apr 13	-555 Apr 23	**-537 May 5**
25	**-735 Jul 1**	**-717 Jul 13**	-699 Jul 23	**-681 Aug 3**	**-663 Aug 14**	-645 Aug 25	**-627 Sep 4**	**-609 Sep 16**	-591 Sep 26	-573 Oct 7	**-555 Oct 17**	-537 Oct 29
26	**-735 Dec 25**	**-716 Jan 6**	**-698 Jan 16**	**-680 Jan 28**	-662 Feb 7	**-644 Feb 18**	**-626 Mar 1**	-608 Mar 11	**-590 Mar 22**	**-572 Apr 2**	-554 Apr 13	**-536 Apr 23**
27	**-734 Jun 21**	-716 Jul 1	-698 Jul 12	**-680 Jul 22**	**-662 Aug 3**	-644 Aug 13	**-626 Aug 24**	**-608 Sep 4**	-590 Sep 15	-572 Sep 25	**-554 Oct 6**	**-536 Oct 17**
28	-734 Dec 15	**-716 Dec 25**	-697 Jan 6	**-679 Jan 16**	**-661 Jan 28**	-643 Feb 7	**-625 Feb 18**	**-607 Mar 1**	-589 Mar 12	**-571 Mar 22**	**-553 Apr 3**	-535 Apr 13
29	-733 Jun 10	-715 Jun 20	-697 Jul 1	**-679 Jul 11**	-661 Jul 23	-643 Aug 2	**-625 Aug 13**	**-607 Aug 24**	-589 Sep 4	**-571 Sep 14**	**-553 Sep 26**	-535 Oct 6
30	-733 Dec 5	-715 Dec 15	-697 Dec 26	-678 Jan 6	-660 Jan 17	-642 Jan 27	-624 Feb 8	-606 Feb 18	-588 Feb 29	-570 Mar 12	-552 Mar 22	-534 Apr 2
31	**-732 Apr 30**	-714 May 11	**-696 May 21**	**-678 Jun 2**	-660 Jun 12	-642 Jun 23	-624 Jul 4	-606 Jul 15	-588 Jul 25	-570 Aug 5	-552 Aug 16	-534 Aug 27
32	-732 Oct 24	**-714 Nov 4**	**-696 Nov 15**	-678 Nov 26	**-660 Dec 6**	**-642 Dec 18**	-624 Dec 28	**-605 Jan 8**	**-587 Jan 19**	-569 Jan 30	**-551 Feb 9**	**-533 Feb 21**
33	**-731 Apr 19**	**-713 May 1**	-695 May 11	**-677 May 22**	**-659 Jun 2**	-641 Jun 13	**-623 Jun 23**	**-605 Jul 5**	-587 Jul 15	-569 Jul 26	**-551 Aug 6**	-533 Aug 17
34	-731 Oct 13	**-713 Oct 24**	**-695 Nov 4**	-677 Nov 15	**-659 Nov 25**	**-641 Dec 7**	-623 Dec 17	**-605 Dec 28**	**-586 Jan 8**	-568 Jan 19	**-550 Jan 29**	**-532 Feb 10**
35	-730 Apr 9	**-712 Apr 19**	**-694 May 1**	-676 May 11	**-658 May 22**	**-640 Jun 2**	-622 Jun 13	-604 Jun 23	**-586 Jul 4**	**-568 Jul 15**	-550 Jul 26	**-532 Aug 5**
36	**-730 Oct 2**	**-712 Oct 13**	-694 Oct 24	**-676 Nov 3**	**-658 Nov 15**	-640 Nov 25	**-622 Dec 6**	**-604 Dec 17**	-586 Dec 28	**-567 Jan 7**	**-549 Jan 19**	-531 Jan 29
37	-729 Mar 30	-711 Apr 9	-693 Apr 20	-675 Apr 30	-657 May 12	-639 May 22	-621 Jun 2	-603 Jun 13	-585 Jun 24	-567 Jul 4	**-549 Jul 15**	**-531 Jul 26**
38	-729 Sep 22	-711 Oct 2	-693 Oct 13	-675 Oct 24	-657 Nov 4	-639 Nov 15	-621 Nov 26	-603 Dec 6	-585 Dec 18	-567 Dec 28	-548 Jan 8	-530 Jan 19

Table 2.9: Distribution of lunar eclipse predictions over the Late Babylonian period.

	13	14	15	16	17	18	19	20	21	22	23	24
1	-530 Jun 15	-512 Jun 25	-494 Jul 7	-476 Jul 17	-458 Jul 28	-440 Aug 7	-422 Aug 19	-404 Aug 29	-386 Sep 9	-368 Sep 20	-350 Oct 1	-332 Oct 11
2	-530 Dec 10	-512 Dec 20	-493 Jan 1	-475 Jan 11	-457 Jan 22	-439 Feb 2	-421 Feb 13	-403 Feb 23	-385 Mar 7	-367 Mar 17	-349 Mar 28	-331 Apr 8
3	-529 Jun 4	-511 Jun 15	-493 Jun 26	-475 Jul 6	-457 Jul 17	-439 Jul 28	-421 Aug 8	-403 Aug 18	-385 Aug 30	-367 Sep 9	-349 Sep 20	-331 Oct 1
4	-529 Nov 29	-511 Dec 10	-493 Dec 21	-475 Dec 31	-456 Jan 12	-438 Jan 22	-420 Feb 2	-402 Feb 13	-384 Feb 24	-366 Mar 6	-348 Mar 17	-330 Mar 28
5	-528 May 24	-510 Jun 4	-492 Jun 14	-474 Jun 26	-456 Jul 6	-438 Jul 17	-420 Jul 28	-402 Aug 8	-384 Aug 18	-366 Aug 30	-348 Sep 9	-330 Sep 20
6	-528 Nov 17	-510 Nov 29	-492 Dec 9	-474 Dec 20	-456 Dec 31	-437 Jan 11	-419 Jan 21	-401 Feb 2	-383 Feb 12	-365 Feb 23	-347 Mar 6	-329 Mar 17
7	-527 May 14	-509 May 25	-491 Jun 4	-473 Jun 15	-455 Jun 26	-437 Jul 7	-419 Jul 17	-401 Jul 29	-383 Aug 8	-365 Aug 19	-347 Aug 30	-329 Sep 10
8	-527 Nov 6	-509 Nov 18	-491 Nov 28	-473 Dec 9	-455 Dec 20	-437 Dec 31	-418 Jan 10	-400 Jan 22	-382 Feb 1	-364 Feb 12	-346 Feb 23	-328 Mar 5
9	-526 Apr 4	-508 Apr 14	-490 Apr 25	-472 May 6	-454 May 17	-436 May 27	-418 Jun 8	-400 Jun 18	-382 Jun 29	-364 Jul 9	-346 Jul 21	-328 Jul 31
10	-526 Sep 27	-508 Oct 7	-490 Oct 19	-472 Oct 29	-454 Nov 9	-436 Nov 20	-418 Dec 1	-400 Dec 11	-382 Dec 23	-363 Jan 2	-345 Jan 14	-327 Jan 24
11	-525 Mar 24	-507 Apr 3	-489 Apr 15	-471 Apr 25	-453 May 6	-435 May 17	-417 May 28	-399 Jun 7	-381 Jun 18	-363 Jun 29	-345 Jul 10	-327 Jul 20
12	-525 Sep 17	-507 Sep 27	-489 Oct 8	-471 Oct 19	-453 Oct 30	-435 Nov 9	-417 Nov 21	-399 Dec 1	-381 Dec 12	-363 Dec 23	-344 Jan 3	-326 Jan 14
13	-524 Mar 12	-506 Mar 24	-488 Apr 3	-470 Apr 14	-452 Apr 24	-434 May 6	-416 May 16	-398 May 27	-380 Jun 6	-362 Jun 18	-344 Jun 28	-326 Jul 9
14	-524 Sep 5	-506 Sep 17	-488 Sep 27	-470 Oct 8	-452 Oct 19	-434 Oct 30	-416 Nov 9	-398 Nov 21	-380 Dec 1	-362 Dec 12	-344 Dec 23	-325 Jan 3
15	-523 Mar 1	-505 Mar 13	-487 Mar 23	-469 Apr 3	-451 Apr 13	-433 Apr 25	-415 May 5	-397 May 16	-379 May 17	-361 Jun 7	-343 Jun 17	-325 Jun 28
16	-523 Jul 27	-505 Aug 8	-487 Aug 18	-469 Aug 29	-451 Sep 9	-433 Sep 20	-415 Sep 30	-397 Oct 12	-379 Oct 22	-361 Nov 2	-343 Nov 13	-325 Nov 24
17	-522 Jan 20	-504 Jan 31	-486 Feb 11	-468 Feb 22	-450 Mar 4	-432 Mar 15	-414 Mar 26	-396 Apr 5	-378 Apr 17	-360 Apr 27	-342 May 8	-324 May 19
18	-522 Jul 16	-504 Jul 27	-486 Aug 7	-468 Aug 17	-450 Aug 29	-432 Sep 8	-414 Sep 19	-396 Sep 30	-378 Oct 11	-360 Oct 21	-342 Nov 2	-324 Nov 12
19	-521 Jan 10	-503 Jan 20	-485 Jan 31	-467 Feb 11	-449 Feb 22	-431 Mar 4	-413 Mar 16	-395 Mar 26	-377 Apr 6	-359 Apr 17	-341 Apr 28	-323 May 8
20	-521 Jul 5	-503 Jul 16	-485 Jul 27	-467 Aug 6	-449 Aug 18	-431 Aug 28	-413 Sep 8	-395 Sep 19	-377 Sep 30	-359 Oct 10	-341 Oct 22	-323 Nov 1
21	-521 Dec 30	-502 Jan 10	-484 Jan 21	-466 Jan 31	-448 Feb 12	-430 Feb 22	-412 Mar 4	-394 Mar 16	-376 Mar 26	-358 Apr 6	-340 Apr 17	-322 Apr 28
22	-520 Jun 24	-502 Jul 5	-484 Jul 15	-466 Jul 27	-448 Aug 6	-430 Aug 17	-412 Aug 28	-394 Sep 8	-376 Sep 18	-358 Sep 30	-340 Oct 10	-322 Oct 21
23	-520 Dec 19	-502 Dec 30	-483 Jan 10	-465 Jan 21	-447 Jan 31	-429 Feb 12	-411 Feb 22	-393 Mar 5	-375 Mar 15	-357 Mar 27	-339 Apr 6	-321 Apr 17
24	-519 May 15	-501 May 26	-483 Jun 5	-465 Jun 17	-447 Jun 27	-429 Jul 8	-411 Jul 19	-393 Jul 30	-375 Aug 9	-357 Aug 21	-339 Aug 31	-321 Sep 11
25	-519 Nov 8	-501 Nov 19	-483 Nov 30	-465 Dec 11	-447 Dec 22	-428 Jan 2	-410 Jan 12	-392 Jan 23	-374 Feb 3	-356 Feb 14	-338 Feb 24	-320 Mar 7
26	-518 May 5	-500 May 15	-482 May 26	-464 Jun 5	-446 Jun 17	-428 Jun 27	-410 Jul 8	-392 Jul 19	-374 Jul 30	-356 Aug 9	-338 Aug 21	-320 Aug 31
27	-518 Oct 28	-500 Nov 7	-482 Nov 19	-464 Nov 29	-446 Dec 11	-428 Dec 21	-409 Jan 1	-391 Jan 12	-373 Jan 23	-355 Feb 2	-337 Feb 14	-319 Feb 24
28	-517 Apr 24	-499 May 4	-481 May 16	-463 May 26	-445 Jun 6	-427 Jun 17	-409 Jun 28	-391 Jul 8	-373 Jul 20	-355 Jul 30	-337 Aug 10	-319 Aug 20
29	-517 Oct 17	-499 Oct 28	-481 Nov 8	-463 Nov 18	-445 Nov 30	-427 Dec 10	-409 Dec 22	-390 Jan 1	-372 Jan 12	-354 Jan 23	-336 Feb 3	-318 Feb 13
30	-516 Apr 13	-498 Apr 24	-480 May 4	-462 May 15	-444 May 26	-426 Jun 6	-408 Jun 16	-390 Jun 28	-372 Jul 8	-354 Jul 19	-336 Jul 29	-318 Aug 10
31	-516 Sep 7	-498 Sep 18	-480 Sep 28	-462 Oct 10	-444 Oct 20	-426 Oct 31	-408 Nov 11	-390 Nov 22	-372 Dec 2	-354 Dec 14	-336 Dec 24	-317 Jan 5
32	-515 Mar 3	-497 Mar 14	-479 Mar 25	-461 Apr 5	-443 Apr 15	-425 Apr 26	-407 May 7	-389 May 18	-371 May 28	-353 Jun 9	-335 Jun 19	-317 Jun 30
33	-515 Aug 27	-497 Sep 8	-479 Sep 18	-461 Sep 29	-443 Oct 10	-425 Oct 21	-407 Oct 31	-389 Nov 12	-371 Nov 22	-353 Dec 3	-335 Dec 14	-317 Dec 25
34	-514 Feb 20	-496 Mar 2	-478 Mar 14	-460 Mar 24	-442 Apr 4	-424 Apr 15	-406 Apr 26	-388 May 6	-370 May 17	-352 May 28	-334 Jun 8	-316 Jun 18
35	-514 Aug 17	-496 Aug 27	-478 Sep 7	-460 Sep 18	-442 Sep 29	-424 Oct 9	-406 Oct 21	-388 Oct 31	-370 Nov 11	-352 Nov 22	-334 Dec 3	-316 Dec 13
36	-513 Feb 9	-495 Feb 20	-477 Mar 3	-459 Mar 13	-441 Mar 25	-423 Apr 4	-405 Apr 15	-387 Apr 26	-369 May 7	-351 May 17	-333 May 29	-315 Jun 8
37	-513 Aug 8	-495 Aug 16	-477 Aug 28	-459 Sep 7	-441 Sep 18	-423 Sep 28	-405 Oct 10	-387 Oct 20	-369 Oct 31	-351 Nov 11	-333 Nov 22	-315 Dec 2
38	-512 Jan 30	-494 Feb 9	-476 Feb 21	-458 Mar 3	-440 Mar 13	-422 Mar 25	-404 Apr 4	-386 Apr 15	-368 Apr 26	-350 May 7	-332 May 17	-314 May 29

Table 2.9 (cont.): Distribution of lunar eclipse predictions over the Late Babylonian period.

	25	26	27
1	-314 Oct 23	-296 Nov 2	-278 Nov 13
2	-313 Apr 19	-295 Apr 29	-277 May 11
3	-313 Oct 12	-295 Oct 22	-277 Nov 3
4	**-312 Apr 7**	**-294 Apr 18**	**-276 Apr 29**
5	**-312 Oct 1**	-294 Oct 12	**-276 Oct 22**
6	**-311 Mar 27**	**-293 Apr 8**	**-275 Apr 18**
7	**-311 Sep 20**	**-293 Oct 2**	-275 Oct 12
8	-310 Mar 16	**-292 Mar 27**	-274 Apr 7
9	-310 Aug 11	-292 Aug 22	-274 Sep 2
10	**-309 Feb 4**	**-291 Feb 15**	-273 Feb 26
11	-309 Jul 31	-291 Aug 11	-273 Aug 22
12	-308 Jan 25	**-290 Feb 4**	**-272 Feb 16**
13	**-308 Jul 20**	-290 Jul 31	-272 Aug 10
14	**-307 Jan 14**	-289 Jan 25	**-271 Feb 4**
15	**-307 Jul 9**	-289 Jul 20	**-271 Jul 30**
16	-307 Dec 4	-289 Dec 16	-271 Dec 26
17	-306 May 30	-288 Jun 9	-270 Jun 21
18	-306 Nov 23	-288 Dec 4	-270 Dec 15
19	**-305 May 20**	-287 May 30	**-269 Jun 10**
20	**-305 Nov 12**	**-287 Nov 23**	-269 Dec 4
21	**-304 May 8**	**-286 May 20**	-268 May 30
22	**-304 Nov 1**	-286 Nov 12	**-268 Nov 22**
23	**-303 Apr 28**	-285 May 9	-267 May 19
24	-303 Sep 22	-285 Oct 3	-267 Oct 13
25	-302 Mar 18	-284 Mar 28	-266 Apr 9
26	-302 Sep 11	-284 Sep 22	-266 Oct 3
27	-301 Mar 7	**-283 Mar 17**	**-265 Mar 29**
28	-301 Sep 1	-283 Sep 11	**-265 Sep 22**
29	**-300 Feb 25**	-282 Mar 7	**-264 Mar 17**
30	-300 Aug 20	**-282 Aug 31**	**-264 Sep 11**
31	-299 Jan 15	-281 Jan 26	-263 Feb 6
32	-299 Jul 10	-281 Jul 22	-263 Aug 1
33	**-298 Jan 4**	-280 Jan 16	-262 Jan 26
34	**-298 Jun 30**	-280 Jul 10	-262 Jul 21
35	**-298 Dec 25**	-279 Jan 4	**-261 Jan 15**
36	**-297 Jun 19**	**-279 Jun 30**	-261 Jul 11
37	**-297 Dec 14**	-279 Dec 24	**-260 Jan 4**
38	-296 Jun 8	**-278 Jun 19**	**-260 Jun 30**

28	29	30
-260 Dec 23	-241 Jan 4	-223 Jan 14
-259 May 21	-241 Jun 1	-223 Jun 11
-259 Nov 13	-241 Nov 25	-223 Dec 5
-258 May 10	**-240 May 20**	**-222 Jun 1**
-258 Nov 3	**-240 Nov 13**	**-222 Nov 25**
-257 Apr 29	**-239 May 9**	**-221 May 21**
-257 Oct 23	-239 Nov 3	**-221 Nov 14**
-256 Apr 17	**-238 Apr 28**	-220 May 9
-256 Sep 12	-238 Sep 24	-220 Oct 4
-255 Mar 8	-237 Mar 20	-219 Mar 30
-255 Sep 1	-237 Sep 14	-219 Sep 23
-254 Feb 26	**-236 Mar 8**	**-218 Mar 20**
-254 Aug 21	**-236 Sep 1**	-218 Sep 12
-253 Feb 16	-235 Feb 26	**-217 Mar 9**
-253 Aug 11	-235 Aug 21	**-217 Sep 1**
-252 Feb 5	-234 Feb 15	-216 Feb 27
-252 Jul 1	-234 Jul 12	-216 Jul 23
-252 Dec 25	-233 Jan 6	-215 Jan 16
-251 Jun 21	-233 Jul 2	-215 Jul 12
-251 Dec 14	**-233 Dec 26**	-214 Jan 5
-250 Jun 10	**-232 Jun 20**	**-214 Jul 4**
-250 Dec 4	-232 Dec 14	**-214 Dec 25**
-249 May 30	**-231 Jun 10**	-213 Jun 21
-249 Nov 23	-231 Dec 4	-213 Dec 15
-248 Apr 19	-230 Apr 30	-212 May 10
-248 Oct 13	-230 Oct 25	-212 Nov 4
-247 Apr 8	**-229 Apr 19**	**-211 Apr 30**
-247 Oct 3	-229 Oct 14	**-211 Oct 24**
-246 Mar 29	-228 Apr 8	**-210 Apr 19**
-246 Sep 22	**-228 Oct 2**	**-210 Oct 14**
-245 Mar 18	-227 Mar 29	-209 Apr 9
-245 Aug 12	-227 Aug 23	-209 Sep 3
-244 Feb 7	-226 Feb 17	-208 Feb 28
-244 Aug 1	-226 Aug 12	-208 Aug 22
-243 Jan 26	-225 Feb 6	**-207 Feb 16**
-243 Jul 21	**-225 Aug 2**	-207 Aug 12
-242 Jan 15	-224 Jan 26	**-206 Feb 5**
-242 Jul 11	**-224 Jul 21**	**-206 Aug 2**

31	32	33	34	35	36
-205 Jan 25	-187 Feb 5	-169 Feb 16	-151 Feb 26	-133 Mar 10	-115 Mar 20
-205 Jul 22	-187 Aug 1	-169 Aug 13	-151 Aug 23	-133 Sep 3	-115 Sep 14
-205 Dec 16	-187 Dec 27	-168 Jan 7	-150 Jan 17	-132 Jan 29	-114 Feb 8
-204 Jun 11	-186 Jun 22	-168 Jul 2	-150 Jul 14	-132 Jul 24	-114 Aug 4
-204 Dec 5	**-186 Dec 16**	**-168 Dec 27**	-149 Jan 7	**-131 Jan 17**	**-113 Jan 29**
-203 May 31	-185 Jun 11	**-167 Jun 21**	**-149 Jul 3**	-131 Jul 13	**-113 Jul 24**
-203 Nov 25	-185 Dec 6	**-167 Dec 16**	**-149 Dec 28**	-130 Jan 7	**-112 Jan 18**
-202 May 20	**-184 May 30**	**-166 Jun 11**	-148 Jun 21	**-130 Jul 2**	**-112 Jul 13**
-202 Nov 14	-184 Nov 24	-166 Dec 6	-148 Dec 16	-130 Dec 27	-111 Jan 7
					-111 Jul 2
-201 Apr 10	-183 Apr 21	-165 May 2	-147 May 12	-129 May 24	
-201 Oct 4	-183 Oct 15	-165 Oct 26	-147 Nov 5	-129 Nov 17	-111 Nov 27
-200 Mar 30	**-182 Apr 10**	**-164 Apr 21**	-146 May 2	**-128 May 12**	**-110 May 24**
-200 Sep 22	**-182 Oct 4**	-164 Oct 14	**-146 Oct 25**	**-128 Nov 5**	-110 Nov 16
-199 Mar 20	-181 Mar 31	**-163 Apr 10**	**-145 Apr 22**	-127 May 2	-109 May 13
-199 Sep 12	-181 Sep 23	**-163 Oct 3**	**-145 Oct 15**	-127 Oct 25	**-109 Nov 5**
-198 Mar 9	-180 Mar 19	-162 Mar 31	-144 Apr 10	-126 Apr 21	-108 May 1
-198 Sep 1	-180 Sep 12	-162 Sep23	-144 Oct 3	-126 Oct 15	-108 Oct 25
-197 Jan 27	-179 Feb 7	-161 Feb 18	-143 Feb 28	-125 Mar 11	-107 Mar 22
-197 Jul 24	-179 Aug 3	-161 Aug 14	-143 Aug 25	-125 Sep 5	-107 Sep 15
-196 Jan 16	**-178 Jan 27**	-160 Feb 7	**-142 Feb 17**	**-124 Feb 29**	-106 Mar 11
-196 Jul 12	**-178 Jul 23**	**-160 Aug 3**	-142 Aug 14	**-124 Aug 24**	**-106 Sep 5**
-195 Jan 5	-177 Jan 16	**-159 Jan 26**	**-141 Feb 7**	-123 Feb 17	**-105 Feb 28**
-195 Jul 1	**-177 Jul 17**	-159 Jul 23	-141 Aug 3	**-123 Aug 13**	**-105 Aug 25**
-195 Dec 25	-176 Jan 6	-158 Jan 16	-140 Jan 27	-122 Feb 7	-104 Feb 18
-194 Jun 20	-176 Jul 1	-158 Jul 12	-140 Jul 22	-122 Aug 2	-104 Aug 13
-194 Nov 15	-176 Nov 26	-158 Dec 7	-140 Dec 18	-122 Dec 29	-103 Jan 8
-193 May 11	**-175 May 21**	**-157 Jun 2**	-139 Jun 12	-121 Jun 23	-103 Jul 3
-193 Nov 5	**-175 Nov 15**	**-157 Nov 26**	-139 Dec 7	**-121 Dec 18**	**-103 Dec 29**
-192 Apr 30	-174 May 11	-156 May 21	**-138 Jun 2**	**-120 Jun 12**	-102 Jun 23
-192 Oct 24	**-174 Nov 4**	**-156 Nov 15**	**-138 Nov 26**	-120 Dec 6	**-102 Dec 18**
-191 Apr 19	-173 May1	-155 May 11	-137 May 22	-119 Jun 2	-101 Jun 13
-191 Oct 13	-173 Oct 24	-155 Nov 4	-137 Nov 15	-119 Nov 15	-101 Dec 7
-190 Mar 10	-172 Mar 21	-154 Apr 1	-136 Apr 11	-118 Apr 23	-100 May 3
-190 Sep 3	-172 Sep 13	-154 Sep 24	-136 Oct 5	-118 Oct 16	-100 Oct 26
-189 Feb 28	-171 Mar 10	**-153 Mar 21**	**-135 Apr 1**	-117 Apr 12	-99 Apr 22
-189 Aug 23	**-171 Sep 3**	-153 Sep 14	**-135 Sep 24**	**-117 Oct 6**	-99 Oct 16
-188 Feb 17	-170 Feb 27	**-152 Mar 9**	**-134 Mar 21**	-116 Mar 31	**-98 Apr 11**
-188 Aug 12	**-170 Aug 23**	**-152 Sep 3**	-134 Sep 14	**-116 Sep 24**	**-98 Oct 6**

Table 2.9 (cont.): Distribution of lunar eclipse predictions over the Late Babylonian period.

	37	38	39	40	41	42
1	**-97 Mar 31**	**-79 Apr 11**	-61 Apr 22	**-43 May 2**	**-25 May 14**	-7 May 24
2	-97 Sep 25	**-79 Oct 5**	**-61 Oct 17**	-43 Oct 27	**-25 Nov 7**	**-7 Nov 18**
3	-96 Feb 19	-78 Mar 2	-60 Mar 12	-42 Mar 23	-24 Apr 3	-6 Apr 14
4	-96 Aug 14	-78 Aug 26	-60 Sep 5	-42 Sep 16	-24 Sep 27	-6 Oct 8
5	-95 Feb 8	**-77 Feb 19**	-59 Mar 2	-41 Mar 13	**-23 Mar 23**	-5 Apr 4
6	**-95 Aug 4**	-77 Aug 15	-59 Aug 25	**-41 Sep 5**	**-23 Sep 16**	-5 Sep 27
7	**-94 Jan 29**	-76 Feb 9	**-58 Feb 19**	**-40 Mar 2**	-22 Mar 13	**-4 Mar 23**
8	-94 Jul 24	-76 Aug 3	**-58 Aug 14**	**-40 Aug 25**	-22 Sep 5	**-4 Sep 15**
9	-93 Jan 18	**-75 Jan 28**	**-57 Feb 9**	-39 Feb 19	**-21 Mar 2**	-3 Mar 13
10	**-93 Jul 13**	-75 Jul 24	-57 Aug 2	**-39 Aug 14**	**-21 Aug 26**	-3 Sep 5
11	-93 Dec 8	-75 Dec 19	-57 Dec 30	-38 Jan 9	-20 Jan 21	-2 Jan 27
12	-92 Jun 3	-74 Jun 14	-56 Jun 24	-38 Jul 6	-20 Jul 16	-2 Jul 27
13	**-92 Nov 26**	**-74 Dec 8**	-56 Dec 18	**-38 Dec 29**	**-19 Jan 9**	-1 Jan 20
14	**-91 May 23**	**-73 Jun 4**	-55 Jun 14	**-37 Jun 25**	**-19 Jul 6**	-1 Jul 17
15	**-91 Nov 16**	-73 Nov 27	**-55 Dec 7**	**-37 Dec 19**	**-19 Dec 29**	**0 Jan 10**
16	**-90 May 13**	-72 May 23	-54 Jun 3	**-36 Jun 13**	**-18 Jun 25**	0 Jul 5
17	**-90 Nov 5**	**-72 Nov 16**	-54 Nov 27	**-36 Dec 7**	-18 Dec 19	**0 Dec 29**
18	-89 Apr 2	-71 Apr 12	-53 Apr 24	-35 May 4	-17 May 15	+1 May 25
19	-89 Sep 27	-71 Oct 7	-53 Oct 18	-35 Oct 29	-17 Nov 9	+1 Nov 19
20	**-88 Mar 21**	**-70 Apr 2**	-52 Apr 12	-34 Apr 23	**-16 May 4**	+2 May 15
21	-88 Sep 15	**-70 Sep 26**	**-52 Oct 7**	-34 Oct 18	**-16 Oct 28**	**+2 Nov 9**
22	**-87 Mar 11**	-69 Mar 22	**-51 Apr 1**	**-33 Apr 13**	-15 Apr 23	**+3 May 4**
23	-87 Sep 4	**-69 Sep 15**	**-51 Sep 26**	-33 Oct 7	**-15 Oct 15**	**+3 Oct 29**
24	**-86 Mar 1**	-68 Mar 11	-50 Mar 26	**-32 Apr 2**	-14 Apr 13	+4 Apr 23
25	-86 Aug 24	**-68 Sep 3**	**-50 Sep 15**	-32 Sep 25	**-14 Oct 6**	**+4 Oct 17**
26	-85 Jan 20	-67 Jan 30	-49 Feb 10	-31 Feb 21	-13 Mar 4	+5 Mar 14
27	-85 Jul 15	-67 Jul 25	-49 Aug 5	-31 Aug 16	-13 Aug 27	+5 Sep 6
28	-84 Jan 9	**-66 Jan 19**	**-48 Jan 31**	-30 Feb 10	-12 Feb 21	**+6 Mar 3**
29	**-84 Jul 3**	-66 Jul 15	-48 Jul 25	**-30 Aug 5**	**-12 Aug 16**	+6 Aug 27
30	**-84 Dec 28**	**-65 Jan 8**	**-47 Jan 19**	**-29 Jan 30**	-11 Feb 9	**+7 Feb 20**
31	-83 Jun 23	**-65 Jul 4**	-47 Jul 15	-29 Jul 26	**-11 Aug 5**	**+7 Aug 17**
32	-83 Dec 17	**-65 Dec 28**	**-46 Jan 8**	-28 Jan 19	**-10 Jan 29**	**+8 Feb 10**
33	-82 May 14	-64 May 24	-46 Jun 5	-28 Jun 15	-10 Jun 26	+8 Jul 7
34	-82 Nov 7	-64 Nov 17	-46 Nov 28	-28 Dec 9	-10 Dec 20	+8 Dec 31
35	**-81 May 3**	**-63 May 14**	-45 May 25	-27 Jun 4	-9 Jun 16	+9 Jun 26
36	**-81 Oct 27**	-63 Nov 7	-45 Nov 18	**-27 Nov 28**	**-9 Dec 10**	**+9 Dec 20**
37	**-80 Apr 21**	**-62 May 3**	-44 May 13	**-26 May 24**	**-8 Jun 4**	+10 Jun 15
38	-80 Oct 16	**-62 Oct 27**	**-44 Nov 7**	-26 Nov 18	**-8 Nov 28**	**+10 Dec 10**

Table 2.9 (cont.): Distribution of lunar eclipse predictions over the Late Babylonian period.

excursion into the sources of the records of the eclipse predictions.

The earliest eclipse predictions in a preserved Astronomical Diary date from 652 BC. Unfortunately, this Diary is badly damaged, and in neither case is it clear whether a time of the eclipse was predicted. Around this period, the Assyrians were also making eclipse predictions. Generally, the Assyrian predictions merely note whether the eclipse was expected to be seen, or whether it would be omitted during the night. Occasionally, as in LAS 63, the watch in which the eclipse was expected to occur was predicted:

> "... [As regards the watch of the lunar eclipse] about which the king, [my lo]rd, wrote to me, its watch will be (kept) tonight, in the morning-watch. The eclipse will occur during the morning-watch. The watch is (kept) [for the safety] of the king, my [lord]; (all) will be well with the king, my lord."
>
> [LAS 63; trans. Parpola (1970: 41)]

This suggests that only very crude estimates of the time of an eclipse could be made by the Assyrians. It is puzzling, therefore, that a Babylonian prediction from 731 BC, about a century earlier, contains a confident prediction that an eclipse would be omitted at 60° after sunrise. We might speculate, therefore, that this prediction was not made in 731 BC, but is in fact a calculation made at a later period. The prediction is contained on LBAT *1414 which, as mentioned above, is part of a large compilation of eclipse records. The latest eclipse on LBAT *1414 dates from 317 BC, and so the data on the tablet must have been compiled after this time. Similarly, all of the preserved eclipse predictions containing the expected time of the eclipse from before the sixth century BC are contained in late compilations. By contrast, however, the eclipse predictions contained on LBAT *1420 only note that an eclipse was omitted during the night. This tablet contains a list of consecutive eclipse observations and predictions from at least 604 BC to 575 BC. It may therefore have been compiled shortly after 575 BC, much earlier than LBAT *1414, and may for that reason contain accounts abstracted from the Diaries is a more verbatim fashion. However, at present, and there is no firm evidence in support of this speculation, and so we must conclude that the Babylonian astronomers developed schemes to predict eclipse times at an earlier period than their Assyrian counterparts.

As I have shown in Section 2.8 above, the predicted eclipse times do not show any significant improvement in accuracy over the whole of the Late Babylonian period, and relate to the moment that the Babylonian astronomers expected the eclipse to begin. The first statement immediately suggests that the same methods of eclipse prediction were used throughout the Late Babylonian period, irrespective of the development of mathematical astronomy, as represented by the ACT material written during the Seleucid period. Furthermore, the fact that the predictions are for the start of the eclipses immediately suggests that they were made with the Saros Cycle, for this is the only short period eclipse cycle in which eclipses recur that have similar magnitudes, durations, and other circumstances. Thus, by adding one Saros period to the time of the beginning of an eclipse, one will obtain the approximate time of the beginning of another eclipse. As mentioned above, the Saros was well known as an eclipse cycle by the Babylonian astronomers, and so it seems virtually certain that it was this cycle that they used. However, the exact method in which the Saros cycle was applied is far from clear. For example, it is not known what procedures were used to take account of the varying length of the day throughout the year which directly affect the predicted times as they are given in relation to sunrise or sunset.

There is no evidence that the eclipse predictions made during the Seleucid period were made using the mathematical astronomy of the ACT texts, despite the fact that calculating the time and visibility of the syzygies was one of its principal goals. Both System A and System B of the ACT lunar theory contain the material necessary for calculating the moment of opposition and conjunction of the Moon and Sun. A lunar ephemeris of System A contains a column, called column "M" in Neugebauer's (1955) terminology, which gives the time of syzygy from sunset. Similarly, System B contains a column M which, in this case, gives the time of syzygy from either sunset or sunrise.[40]

[40] For a detailed account of the workings of Systems A and B, see Neugebauer (1975) and the references therein.

However, neither System appears to allow the duration of an eclipse, and hence the time of first contact given in the predicted records, to be calculated. As Moesgaard (1980) has noted, the duration of an eclipse is related to its magnitude. It is therefore possible that column Ψ of both Systems A and B, which characterises the magnitude of an eclipse, could be manipulated in such a way as to obtain its duration. As I shall discuss in Section 6.4 below, the Chinese used a simple relationship of this kind in making their eclipse predictions. However, there is no documentary evidence of its use in the Babylonian ACT texts. Therefore it seems clear that the ACT methods played no part in the prediction of eclipses for the Diaries and related texts.

Finally, let me make some remarks about the prediction of solar eclipses by the Babylonians. To make successful predictions of solar eclipses it is necessary to take into account the effect of lunar parallax, and the geographical location of the observer on the Earth's surface. There is no evidence that the Babylonians ever achieved such a level of understanding of eclipses. Instead, it would appear that the Babylonian astronomers merely treated solar eclipses in the same fashion as lunar eclipses, being content to be able to distinguish between times when an eclipse was possible, from those when they were not (Aaboe 1972). Thus, the Saros was again used, although the distribution of eclipse possibilities within the Saros differed from that for lunar eclipses.

To summarize, it would seems that the Babylonian astronomers identified the Saros cycle by at least the seventh century BC, and probably earlier. They used this cycle to make all of their lunar and solar eclipse predictions throughout the Late Babylonian period, distributing 38 eclipse possibilities within each cycle. For lunar eclipses, this distribution appears to have been reformed three times: around 250 BC, around 200 BC, and finally, around 110 BC. The scheme used between about 250 BC and 200 BC is the same as that found on the so-called Saros Canon which lists the dates of eclipse possibilities from about 550 BC to 250 BC. Previously, it had been assumed, for example by Britton (1993), that the scheme on the Saros Canon had been used in this period, but the present investigation shows that this was not the case. Instead, the Saros Canon contains a projection back in time of the scheme that was introduced around 250 BC.

Chapter 3

Ancient Europe (c. 200 BC – AD 364)

A Hellenophile suffers from a form of madness that blinds him or her to historical truth and creates in the imagination the idea that one of several false propositions is true. The first is that the Greeks invented science; the second is that they discovered a way to truth, the scientific method, that we are now successfully following; the third is that the only real sciences are those that began in Greece; and the fourth (and last?) is that the true definition of science is just that which scientists happen to be doing now, following a method or methods adumbrated by the Greeks, but never fully understood or utilized by them.
— David Pingree, *Hellenophilia versus the History of Science*, 1992

3.1 Introduction

Given the great interest shown in Ancient Greek astronomy among historians of science, it is perhaps at first surprising how few actual astronomical observations made by Greek astronomers are known.[1] In contrast to the many hundreds of astronomical texts recovered from Babylon, there are only a handful of Greek observations that have been preserved. The interest shown among historians in Ancient Greek astronomy is mainly due to three other factors: the achievements made by astronomers such as Hipparchus and Ptolemy in mathematical astronomy, the many cosmological speculations found in the writings of philosophers,[2] and the fact that source material has been widely available for study for many years, unlike most of the Babylonian material.

Around the turn of the present century a number of astronomers made investigations into the secular accelerations of the Sun and Moon, which are related to long-term changes in the Earth's rate of rotation.[3] Principal among their methods of analysis was an investigation of historical observations of eclipses. The importance of an eclipse observation in determining the secular accelerations increases approximately quadratically with time, and so the eclipse records from ancient Europe were viewed with great interest. These eclipse records were found in two main types of source: non-technical accounts in the Greek and Latin classics, and detailed observations contained in the works of astronomers.

Many of the eclipse records in the classics are very vague. In many cases, they do not even explicitly mention that an eclipse took place. For example, Herodotus describes an event during a battle which has often been interpreted as a solar eclipse:

> "... after five years of indecisive warfare, a battle took place in which the armies had already engaged when day was suddenly turned into night. This change from daylight to darkness had

[1]By Greek astronomers I am referring to the astronomers who wrote in that language, rather than their geographical origin. For example, Ptolemy lived and worked around the city of Alexandria in Roman Egypt.

[2]Such cosmological speculations are largely absent from the preserved Babylonian sources, which may explain why they have, on the whole, received far less attention among scholars.

[3]For example, Newcomb (1878), Ginzel (1899), and Fotheringham (1920a, 1920b). See Stephenson (1997b) for an historical overview.

been foretold to the Ionians by Thales of Miletus, who fixed the date for it in the year in which it did, in fact, take place."

[*Historia*, I, 74; trans. de Sélincourt (1979: 70)]

Personally, I remain to be convinced that this event was indeed a real solar eclipse and not either a meteorological phenomenon or an apocryphal story.

In common with many of the eclipse accounts in the classics, no date is given for the "Eclipse of Thales". A number attempts have been made to try to establish the date of this event, most recently by Hartner (1969) and Panchenko (1994), but none have proved fully successful (Stephenson & Fatoohi 1997). Timings of the eclipses are never given in the accounts in the classics, and so they will not be considered further in this study.[4]

Detailed timed eclipse observations from Ancient Europe and only found in two works: Ptolemy's *Almagest* and Theon of Alexandria's commentary on the *Almagest*. These will be the subject of the remainder of this chapter. Much of the following discussion is based upon my article, Steele (1998e).

3.2 Observations of Lunar Eclipses in Ptolemy's *Almagest*

Ptolemy's great astronomical treatise, usually known as the *Almagest*, has probably aroused more interest among historians of astronomy than any other work from before the Renaissance. Written by Claudius Ptolemaeus (c. AD 100-175) in Alexandria, the *Mathematike Syntaxis*, to give the work its Greek name, was first published sometime between AD 150 and AD 161 (Toomer 1984). The *Almagest* was a comprehensive treatise of mathematical astronomy, containing, in the words of Pedersen (1974: 11), a "brilliant exposition of everything achieved by Ptolemy himself and by the most remarkable of his predecessors among the Greek astronomers." For over one thousand years since its composition it was the standard textbook of astronomy and had a profound influence on both Arab and European astronomy until as late as the sixteenth century AD. In addition to the *Almagest*, Ptolemy wrote a number of other works. Most important among these are the *Planetary Hypotheses* and the *Handy Tables*, which give a general background to the astronomy of the *Almagest* and simplified rules for its use, and the *Tetrabiblos* (Pedersen 1974). During the Middle Ages, it was for this last work that Ptolemy was well known. It is largely a work of astrology, detailing how the astronomical predictions made from the *Almagest* can be used to deduce the influences of the various heavenly bodies on the Earth.

Although primarily a work of astronomical theory, a number of observations are quoted in the *Almagest* as illustrative examples of the methods that Ptolemy used in calculating the parameters for his theories.[5] These include observations of lunar eclipses, occultations, equinoxes, and over one thousand stars. The reliability of Ptolemy's observations has been questioned since the nineteenth century.[6] Thus, in his work *The Crime of Claudius Ptolemy*, Robert Newton concludes that "Ptolemy is not the greatest astronomer in antiquity, but he is something still more unusual: He is the most successful fraud in the history of science" (Newton 1977: 379). However, Newton's statistical arguments for most of the observations in the *Almagest* being fraudulent have been heavily criticised by Swerdlow (1979). The most recent evaluation of Ptolemy's solar and lunar observations is by Britton (1992). He concludes that the observations described by Ptolemy were only a small sample of those that he used in deriving the parameters for his theories.

The astronomical observations reported by Ptolemy in his *Almagest* fall into three distinct groups: those said to have been observed in Babylon, those observed by early Greek astronomers, and those

[4]For recent discussions of the eclipse records in the Greek and Latin classics, see Newton (1970) and Stephenson (1997b).

[5]For details of Ptolemy's theories, see Pedersen (1974) and Neugebauer (1975).

[6]See Britton (1992: ix–x) for an historical overview

observed by Ptolemy and his contemporaries. It would appear that Hipparchus was the source of most of the observations in the first two categories, as Ptolemy himself notes:

> "Hence it was, I think, that Hipparchus, being a great lover of truth, for all the above reasons, and especially because he did not yet have in his possession such a groundwork of resources in the form of accurate observations from earlier times as he himself has provided to us, although he investigated the theories of the Sun and the Moon, and, to the best of his ability, demonstrated with every means at his command that they are represented by uniform circular motions, did not even make a beginning in establishing theories for the five planets, not at least in his writings which have come down to us. All that he did was to make a compilation of the planetary observations arranged in a more useful way, and to show by means of these that the phenomena were not in agreement with the hypotheses of the astronomers of that time."
>
> [*Almagest*, ix, 2; trans. Toomer (1984: 421)]

This suggests that Hipparchus made an extensive compilation of astronomical observations from before his time, and perhaps sheds some light on the curious statement made by Pliny that,

> "... the courses of both stars (the Sun and Moon) for 600 years were prophesied by Hipparchus, whose work embraced the calendar of the nations and the situations of places and aspects of the peoples — his method being, on the evidence of his contemporaries, none other than full partnership in the designs of nature."
>
> [*Historia Naturalis*, ii, 9; trans. Rackham (1937: 203)]

As Neugebauer (1975) has plausibly suggested, Pliny was probably mistaken in attributing Hipparchus with calculating 600 years of "the courses of both stars", by which he probably means eclipses, for this would be a monumental task without any practical application. Instead, Hipparchus presumably made a compilation of eclipse observations for the six hundred years before his time.

In deducing the basic parameters for his lunar model, Ptolemy chose to use observations of lunar eclipses for

> "... these are the only observations which allow one to determine the lunar position precisely; all others, whether they are taken from passages [of the moon] near fixed stars, or from [sightings with] instruments, or from solar eclipses, can contain a considerable error due to parallax."
>
> [*Almagest*, iv, 1; trans. Toomer (1984: 173)]

Accordingly, Ptolemy describes no observations of solar eclipses, only 18 lunar obscurations. Rather than quote the records in full here, the observed details of each eclipse are summarized in Table 3.1, together with a reference to the page of the full translation of the record in Toomer (1984). Before discussing any of these observations in detail, it is necessary to make a few general remarks about the nature of the records.

Ptolemy used his own chronology throughout the *Almagest*. This commenced with the beginning of the reign of Nabonassar (equivalent to 26 February 747 BC) for, as he says, "that is the era beginning from which the ancient observations are, on the whole, preserved down to our own time."[7] He also uses the Egyptian year of twelve 30 day months followed by 5 extra days, making a total of 365 days. This system, which allows accurate day counts to be made with ease, is probably due to Hipparchus (Toomer 1996). In addition, when discussing observations made during the night, Ptolemy often gives a double date to avoid confusion.

Most of the times quoted by Ptolemy are in seasonal hours. A seasonal hour is defined as being one-twelfth of the length of the day or night, and is thus dependent on the time of year. Ptolemy's first step in using these times is to convert them to equinoctial hours, a constant unit of time defined as one-twentyfourth of the length of time between two consecutive midnights. Ptolemy uses Alexandria as his meridian and so in his analysis of the lunar eclipse observations, reduces all times to Alexandrian local time.

[7] *Almagest*, iii, 7; trans. Toomer (1984: 166)

Date	Location	Observation	Page in Toomer (1984)
-720 Mar 19	Babylon	The eclipse began, it says, well over an hour after moonrise, and was total	191
-719 Mar 8	Babylon	The [maximum] obscuration, it says, was 3 digits from the south exactly at midnight	191–192
-719 Sep 1	Babylon	The eclipse began, it says, after moonrise, and the [maximum] obscuration was more than half [the disk] from the north	192
-620 Apr 21	Babylon	... at the end of the eleventh hour in Babylon, the moon began to be eclipsed; the maximum obscuration was $\frac{1}{4}$ of the diameter from the south	253
-522 Jul 16	Babylon	1 [equinoctial] hour before midnight at Babylon, the moon was eclipsed half its diameter from the north	253
-501 Nov 19	Babylon	... when $6\frac{1}{3}$ equinoctial hours of the night had passed; at this eclipse the moon was, again, obscured from the south $\frac{1}{4}$ of it's diameter	208
-490 Apr 25	Babylon	... at the middle of the sixth hour [of night]. It is reported that at this eclipse the moon was obscured 2 digits from the south	206–207
-382 Dec 23	Babylon	... a small section of the moon's disk was eclipsed from the summer rising-point when half an hour of night was remaining	211–212
-381 Jun 18	Babylon	[the moon] was eclipsed from the summer rising-point when the first hour [of night] was well advanced	212
-381 Dec 12	Babylon	[the moon] was totally eclipsed, beginning from the summer rising-point, after 4 hours [of night] had passed	213
-200 Sep 22	Alexandria	In this eclipse the moon began to be obscured half an hour before it rose, and its full light was restored in the middle of the third hour [of night].	214
-199 Mar 19	Alexandria	... it began when $5\frac{1}{3}$ hours of night had passed, and was total	214
-199 Sep 12	Alexandria	... it began when $6\frac{2}{3}$ hours of the night had passed, and was total	215
-173 May 1	Alexandria	... from the beginning of the eighth hour till the end of the tenth hour in Alexandria, there was an eclipse of the moon which reached a maximum obscuration of 7 digits from the north	283
-140 Jan 27	Rhodes	... at the beginning of the fifth hour [of night] in Rhodes, the moon began to be eclipsed; the maximum obscuration was 3 digits from the south	284
+125 Apr 5	Alexandria	... $3\frac{3}{5}$ equinoctial hours before midnight. At this eclipse too the moon was obscured $\frac{1}{6}$ of its diameter from the south	206
+133 May 6	Alexandria	We computed the exact time of mid-eclipse as $\frac{3}{4}$ of an hour before midnight. It was total.	198
+134 Oct 20	Alexandria	We computed that mid-eclipse occurred 1 equinoctial hour before midnight. [The moon] was eclipsed $\frac{5}{6}$ of its diameter from the north	198
+136 May 5	Alexandria	We computed that mid-eclipse occurred 4 equinoctial hours after midnight. [The moon] was eclipsed half of its diameter from the north	198

Table 3.1: Eclipse observations in Ptolemy's *Almagest*.

I will now proceed to consider each of the three sets of eclipse observations reported by Ptolemy in his *Almagest* in turn.

3.2.1 Babylonian Observations

The earliest ten lunar eclipses reported in the *Almagest* are all said to have been observed in Babylon. According to Ptolemy, Babylon is $\frac{5}{6}$ of an hour, or 12.5 degrees, to the east of Alexandria. The true difference in longitude is 14.5 degrees. This discrepancy reflects one of the greatest problems faced by the ancient Greek astronomers: the determination of geographical longitudes.

As I have discussed in Chapter 2, there are many eclipse observations recorded on the Late Babylonian Astronomical Texts recovered from the site of Babylon during the last century. The Babylonian Astronomical Diaries provide the most obvious source from which Hipparchus could have made his compilation of historical eclipse records (Toomer 1988). Perhaps even more useful would have been the lists of eclipses compiled by the Babylonian astronomers. However, there are great differences in style between the eclipses reported in the *Almagest* and those in the Babylonian Diaries and Eclipse Lists. This is illustrated by the following two examples. The first is a report of the eclipse of 25 April 491 BC, as reported by Ptolemy, and the second is a report of the eclipse of 6 October 555 BC contained in a Babylonian eclipse list.

> "The first eclipse we used is the one observed in Babylon in the thirty-first year of Darius I, Tybi 3/4 in the Egyptian calendar, at the middle of the sixth hour [of night]. It is reported that at this eclipse the moon was obscured 2 digits from the south..."
>
> [*Almagest*, iv, 9; trans. Toomer (1984: 206–207)]

> "Month VII, the 13th, in 17° on the east side, all was covered; 28° maximal phase. In 20° it cleared from east to west. Its eclipse was red. Behind the rump of Aries it was eclipsed. During onset, the north wind blew, during clearing, the west wind. At 55° before sunrise."
>
> [LBAT *1419, Obv. VI', 2'–8'; trans. Sachs & Hunger (1998)]

The first difference between the two styles of record is in the chronology used. The Babylonians used a luni-solar calendar. The month began on the night when the lunar crescent was first visible and lasted for 29 or 30 days. There were twelve months in most years and an intercalary month was inserted as necessary to keep the calendar in line with the seasons. In principle, Hipparchus could easily have constructed tables detailing the Babylonian calendar, as a complete running record of the month lengths and distribution of the intercalary months was preserved in the Astronomical Diaries. In fact, it seems likely that the Babylonian astronomers would have extracted such details of the calendar themselves for use in constructing their astronomical ephemerides, although no such tables are extant.

The other striking difference between the two records is in the units they use to state the time of the eclipse. As discussed in Section 2.4 above, the cuneiform records give the time of an eclipse in *bēru* and UŠ. However, Ptolemy generally gives the time of the Babylonian observations in seasonal hours. If we are to assume, as seems unavoidable, that the Astronomical Diaries or the Eclipse Lists were the source of the Babylonian observations in the *Almagest*, it is necessary to ask how the times came to be converted into seasonal hours. Clearly it would not make sense to assume that Ptolemy himself did this as his first step in analysing the records is to convert the seasonal hours back into equinoctial hours. This would suggest that the conversion was done either by the Babylonians themselves, or by Hipparchus when he compiled his list of eclipses.

Fotheringham (1932) was of the opinion that the conversion was made by the Babylonians using the so called "Ivory Prism". This is a small fragment of a prism, now in the British Museum, on which he concluded that a scheme for converting seasonal hours to *bēru* and UŠ was written. Fotheringham's reconstruction of the Ivory Prism has been published by Langdon (1935). The scheme was based on a ratio for the length of the longest to the shortest day of 2:1. As noted in Section 2.4, this ratio is very inaccurate for the latitude of Babylon; nevertheless there are examples of it found in Babylonian history down to the sixth century BC. However, a ratio of 3:2, which is a much better approximation to the true value, was also used in Babylon from well before this period.

Fotheringham (1932) claimed that his interpretation of the Ivory Prism was confirmed by the only record of an eclipse in the *Almagest* that is also preserved on an extant Babylonian tablet.[8] This is the eclipse of 16 July 523 BC, found on the Babylonian tablet BM 33066 and in the *Almagest*, v, 14:

> "Year 7 (Kambyses), month IV, night 14, $1\frac{2}{3}$ *bēru* after sunset, the moon makes a total eclipse, (but) a little is left over; north (wind) went."
>
> [BM 33066; trans. Huber (1973: 25)]

> "Again, in the seventh year of Kambyses, which is in the 225th year from Nabonassar, Phamenoth 17/18 in the Egyptian calendar, 1 hour before midnight at Babylon, the moon was eclipsed half its diameter from the north. Thus the eclipse occurred about $1\frac{5}{6}$ equinoctial hours before midnight at Alexandria."
>
> [*Almagest*, v, 14; trans. Toomer (1984: 253)]

Fotheringham (1932) assumes that the time given in the *Almagest* is 1 seasonal hour before midnight, or 5 seasonal hours after sunset. Using his restoration of the Ivory Prism, he finds that 5 seasonal hours are equal to 1 *bēru* and 20 UŠ, or $1\frac{2}{3}$ *bēru*. However, there are a number of problems with his argument. Toomer (1984) believes that the time given by Ptolemy is in equinoctial hours as Ptolemy merely adds his time difference between Babylon and Alexandria ($\frac{5}{6}$ hour) to obtain a time of "$1\frac{5}{6}$ equinoctial hours at Babylon". Furthermore, the time of the eclipse given in the cuneiform record is for the start of the eclipse, whereas Ptolemy has the time of its middle. This would mean that Ptolemy would have had to have mistaken the phase of the eclipse and to have then failed to change from seasonal to equinoctial hours before making his calculations. In addition, Huber (1973) has suggested that the Babylonian record may in fact represent a prediction rather than an observation; the tablet certainly contains other predicted elements and we can compute that the eclipse only had a magnitude of just over 0.5 so the claim that the eclipse was almost total does not make sense if it was indeed observed. Most Babylonian estimates of magnitude are fairly accurate (Stephenson & Fatoohi 1994a).

Without the eclipse of 523 BC there is no support for Fotheringham's conclusions. It seems very unlikely that the Babylonians would have used the scheme on the Ivory Prism to convert from equinoctial to seasonal time if they translated the Babylonian records for Hipparchus. By this period they had long abandoned the primitive ratio of 2:1 for the longest to the shortest day and had developed much more accurate schemes based on the 3:2 ratio in their texts of mathematical astronomy (Neugebauer 1955). If it was the Babylonians who made these conversions then they would surely have used these later schemes.

The other alternative is that the Babylonian observations came to Hipparchus in their original form and the Greeks converted the timings into seasonal hours. All of the eclipses observed by Greek astronomers earlier than Ptolemy are timed in seasonal hours and so this may have been standard Greek practice. Perhaps Hipparchus himself made the conversion into seasonal hours so that his compilation of eclipse records, which presumably included contemporary Greek as well as Babylonian observations, had a uniform style.

Table 3.2 compares the times of the Babylonian eclipse observations reported by Ptolemy with the results of modern computation. In each case I have used Ptolemy's interpretation of the timings,[9] despite the fact that in some cases, for example the eclipses on the 1st September 720 BC and the

[8] This is not strictly true, for the tablet LBAT *1429 contains records of three further eclipses reported by Ptolemy: 23rd December 383 BC, 18th June 382 BC, and 12th December 382 BC. However, the portion of the tablet containing these three records is so badly damaged as to render it virtually useless.

[9] For example, Ptolemy assumes that the eclipse on the 19th May 721 BC, which is described as beginning "well over an hour after moonrise", started at $1\frac{1}{2}$ hours after moonrise.

Date	Contact	Local Time (h) Observed	Computed
-720 Mar 19	1	19.20	19.58
-719 Mar 8	M	0.00	23.61
-620 Apr 21	1	4.60	4.33
-522 Jul 16	M	23.00	23.59
-501 Nov 19	M	23.58	0.18
-490 Apr 25	M	23.55	22.77
-382 Dec 23	1	6.42	7.16
-381 Jun 18	1	19.55	19.93
-381 Dec 12	1	21.67	21.37

Table 3.2: Babylonian eclipse times reported by Ptolemy.

19th November 502 BC, the descriptions of the observations are very vague and open to other interpretations. Where necessary I have made the conversion from seasonal to equinoctial hours using modern computations of the length of the night. Fotheringham (1920a) and others have assumed that Ptolemy was mistaken about the phase of some of the eclipses and have chosen various alternatives. However, it seems better to initially follow Ptolemy in his interpretations, and then to consider other possibilities afterwards.

It is important to note at this point that the eclipse in 323 BC could not have been observed in Babylon as the Moon would have set before the eclipse began. Therefore Ptolemy's claim that the eclipse was observed to begin half an hour before sunrise clearly cannot be true. Perhaps the Babylonian astronomers predicted an eclipse for this time and this was mistaken for an observation when it was transmitted to the Greeks. Accordingly, this record will be ignored in the subsequent analysis of the errors in the observed times.

There does not appear to be any significant evidence for any systematic errors in the times of the Babylonian eclipses quoted by Ptolemy; the mean error is +0.04 hours. The typical accuracy of these timings is 0.44 hours. In Chapter 2 I found that the accuracy of the eclipse times preserved in the Late Babylonian Astronomical Texts was dependent upon the length of the time interval measured. The average length of the time interval measured in the eclipses quoted by Ptolemy is about $3\frac{1}{4}$ hours. The accuracy of a time intervals of this length recorded on the Late Babylonian Astronomical Texts is just under half an hour. Thus, the Babylonian eclipse timings reported by Ptolemy are of comparable accuracy to those found in the cuneiform record. This not only suggests that there was no significant loss of accuracy when the Babylonian times were converted into seasonal hours,[10] but also adds strength to the argument that the observations are indeed genuine.

As Britton (1992) has shown, it is possible to reduce the errors in the times given by Ptolemy for the Babylonian observations on 19 March 721 BC, 1 September 720 BC, 19 November 502 BC and 18 June 382 BC by assuming an error in either Ptolemy's interpretation of the time of the eclipse or of the phase at which the time was measured. The most plausible of these corrections is for the eclipse of 721 BC which gives a time of "well over an hour after moonrise." As the Babylonians customarily made their timings with respect to sunset or sunrise it seems possible that Ptolemy had made a mistake in referring to moonrise. If sunset was assumed then the error would be reduced by 0.22 hours. Another possible correction to Ptolemy's reports is to assume that he was mistaken in his belief that the times were seasonal hours. However, there is no firm evidence in favour of making these corrections.

[10]This strongly implies that the inaccurate Ivory Prism could not have been used to make these conversions.

Date	Contact	Local Time (h) Observed	Computed
-200 Sep 22	4	20.58	20.46
-199 Mar 19	1	23.33	23.05
-199 Sep 12	1	0.63	0.61
-173 May 1	1	0.89	0.49
-173 May 1	4	3.57	3.11
-140 Jan 27	1	21.69	20.71

Table 3.3: Early Greek eclipse times reported by Ptolemy.

3.2.2 Early Greek Observations

There are five lunar eclipses observed by early Greek astronomers recorded in the *Almagest*. They range in date from 201 BC to 141 BC, and, with the exception of the final one, they were observed in Alexandria (latitude = +31.22, longitude = -29.92). The eclipse in 141 BC was observed in Rhodes (latitude = +36.43, longitude = -28.23) by Hipparchus; the names of the other observers are not given. Ptolemy's source for these observations was probably once again Hipparchus as he notes that most of them were also used by him.

Seasonal hours were used for all of the time measurements by the early Greek astronomers given in the *Almagest*. They are known to have been in common use in antiquity, as is shown by the water clock constructed by Ctesibius at the beginning of the third century BC. This clock, which is described by Vitruvius,[11] was marked with different scales for each of the Egyptian months to make allowance for the changing length of the seasonal hour. Accordingly, if we are to postulate that the early Greek astronomers measured the time of the observations with whichever clock was available to them, then it would seem quite possible that this would measure seasonal hours. Despite the fact that equinoctial hours were used by the astronomers in their theories and so any observations must have been converted into this system, it seems reasonable to suppose that in compiling any lists of observational records, the original observations, in seasonal hours, would have been copied.

It is interesting to note that the record of the eclipse in 201 BC not only gives the time that the eclipse was observed to finish, but also an estimate of the unobserved time it began, this being half an hour before the Moon rose. This moment was presumably calculated by timing the later phases of the eclipse and estimating its duration. This was also often the practice of the Babylonian astronomers. They could calculate this time with an accuracy of about half an hour (Steele & Stephenson 1997). In this case the Greek astronomer was only 0.25 hours late in his estimate.

The eclipse timings made by the early Greek astronomers are listed in Table 3.3. Unlike the Babylonian observations, there appears to be a systematic error in the times of all of the observations made by the early Greek astronomers. The mean value of this error is -0.38 hours. The time of the start of the eclipse in 141 BC is almost an hour early. This is significantly less accurate than the other records in this group which suggests that there may be some problem with the record. Britton (1992) has suggested that the time may relate to the middle of the eclipse rather than the beginning. This would reduce the error to -0.09. However, there is no real justification for making this correction and so it seems better simply to say that there appears to be something wrong with this record, and to ignore it in calculating the mean error, which now reduces to -0.25. Nevertheless, even after discarding this record there is still a significant systematic error in the times of these early Greek observations.

[11] *De Architectura*, ix, 8. See, for example, the translation of Granger (1934: 259–267).

Date	Contact	Local Time (h) Observed	Computed
+125 Apr 5	M	20.40	20.65
+133 May 6	M	23.25	22.86
+134 Oct 20	M	23.00	22.93
+136 May 5	M	4.00	3.30

Table 3.4: Later Greek eclipse times reported by Ptolemy.

3.2.3 Later Greek Observations

There are four eclipse observations between AD 125 and AD 136 recorded in the *Almagest*. Those in AD 133, AD 134, and AD 136 are all said by Ptolemy to have been "very carefully observed by us in Alexandria".[12] The eclipse of AD 125 was also observed in Alexandria, but the name of the observer is not given. It is possible that this was also Ptolemy, but Toomer (1984) suggests that the mathematician Theon, who was the source of some of the planetary observations of this period and is possibly to be identified as Theon of Smyrna, may have been the observer.

All four of these records give the time of the middle of the eclipse in equinoctial hours. Ptolemy gives no details of how he computed the mid-point of the eclipses. Presumably the time of the beginning and end of each eclipse was measured and the mid-point taken. Ptolemy also uses equinoctial hours in his astrological work, the *Tetrabiblos*. For example, when discussing the astrological interpretation of eclipses he states that:

> "For when these data are examined, if it is a solar eclipse, we shall understand that the predicted event lasts as many years as the equinoctial hours which we discover, and if a lunar eclipse, as many months."
>
> [*Tetrabiblos*, ii, 6; trans. Robbins (1940: 167)]

In case the reader uses seasonal hours, however, Ptolemy explains how the conversion to equinoctial hours may be made. Over one hundred years earlier, Manilius, in his astrological poem the *Astronomica* (iii, 218–275), had also stressed the importance of using equinoctial hours in astrology. However, Neugebauer & van Hoesen (1959) have concluded that seasonal hours were usually being used in Greek horoscopes until well after Ptolemy's time.

Table 3.4 lists the observed and computed times of these four eclipses. As with the early Greek observations there appears to be a systematic error; the mean error in the observed times is -0.23 hours. However, the eclipse in AD 136 is considerably less accurate than the other three eclipses, and without it the systematic error is reduced to -0.07 hours. The typical accuracy of these timings is 0.35 hours, but this is reduced to 0.24 hours if the eclipse of AD 136 is removed. It should be remembered, however, that this is a small sample of data.

3.3 Observation of a Solar Eclipse by Theon of Alexandria

Little is known of Theon of Alexandria. It is believed that he was active between about AD 360 and AD 380, and that he was a non-Christian living in Alexandria (Toomer 1977). Though his own contributions to the development of mathematics and astronomy were fairly modest, he became very influential through the editions, in effect rewritings, and commentaries of works by authors such as Ptolemy and Euclid that he produced. It would appear that Theon was involved in teaching these works, and it seems that he may have written his commentaries for the benefit of his students. Perhaps the best known of Theon's works are his commentaries on Ptolemy's *Almagest* and *Handy Tables*, and

[12] *Almagest*, iv, 6; trans. Toomer (1984: 198)).

	Local Time (h)	
Contact	Observed	Computed
1	14.83	15.25
M	15.80	16.16
4	16.50	16.99

Table 3.5: Timings of the solar eclipse observed by Theon of Alexandria.

a larger treatise that attempts to show how Ptolemy derived the *Handy Tables* from his theories in the *Almagest* (Jones 1996).

As part of his commentary on the *Almagest*, Theon compares the circumstances of a solar eclipse that he himself has observed, with those calculated by Ptolemy's methods. He describes the eclipse, which he observed on the 16th June 364 AD, as follows:

> "... the time reckoned by civil days and equinoctial hours of the exact ecliptic conjunction which we have discussed, and which took place according to the Egyptian calendar in the 1112th year from the reign of Nabonassar $2\frac{5}{6}$ equinoctial hours after midday on the 24th of Thoth, and according to the Alexandrine calendar reckoned by simple civil days in the 1112th year of the same reign $2\frac{5}{6}$ equal or equinoctial hours after midday on the 22nd of Payni ... And moreover we observed with the greatest certainty the time of the beginning of contact, reckoned by civil and apparent time as $2\frac{5}{6}$ equinoctial hours after midday, and the time of the middle of the eclipse as $3\frac{4}{5}$ hours, and the time of complete restoration as $4\frac{1}{2}$ hours approximately after the said midday of the 22nd of Payni."
>
> [Theon of Alexandria 332; trans. Fotheringham (1920b)]

Table 3.5 lists Theon's observed times and those given by modern computations. It is immediately clear that all of the contact timings are early by just under half an hour.[13] However, despite this systematic error, these three timings are very self-consistent. It is unfortunate, therefore, that Theon did not record any more eclipse observations.

3.4 Accuracy of the Observed Times

The errors in the observed times of the eclipses recorded in Greek sources are shown in Figure 3.1. The three groups of eclipse observations recorded in the *Almagest* show distinct differences in their variations from modern computations. Unsurprisingly, given their age, the Babylonian observations appear to be the least accurate of the three groups. However, unlike both the early and later Greek observations, they show negligible systematic errors in their timings. Indeed the systematic errors in the timing of the early Greek observations is very serious and must lead us to question how representative these records are of the observations being made at this period. The systematic error in the later Greek observations is almost wholly caused by the time of the eclipse in AD 136. This was one of the eclipses said to have been observed by Ptolemy himself, but nevertheless it is necessary to question his own interpretation of it.

Given that the observations in the *Almagest* represent only a small proportion of those available to Ptolemy and that he probably used some form of averaging in deriving his parameters (Britton 1992), what was his criteria for choosing them? In particular, why did he switch from using Babylonian to Greek eclipse observations after the third century BC? Presumably Hipparchus' collection of Babylonian eclipses would continue up until its compilation in the middle of the second century BC. It would appear that Ptolemy preferred to use Greek observations where they were available to him. This may

[13]The cause of this systematic error is not known. The simplest explanation is that Theon used a poorly calibrated clock to time the eclipse.

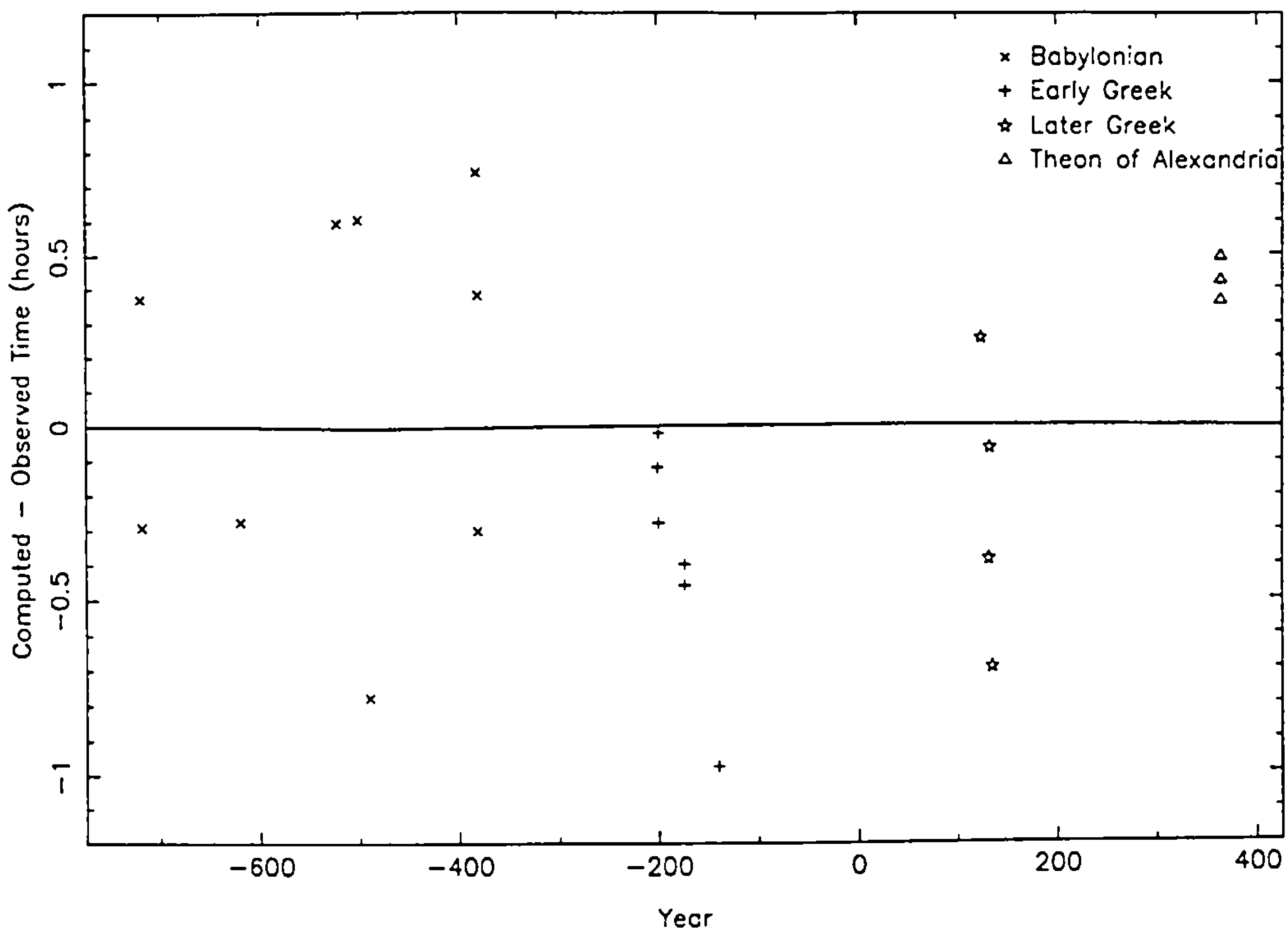


Figure 3.1: Error in the observed eclipse times recorded in Greek sources.

have been for practical reasons; Ptolemy would have known that his correction for the difference in longitude between Babylon and Alexandria was not exact and that this could seriously affect the derivation of his parameters. He may also have been suspicious of the reliability of the Babylonians as astronomers as he is unlikely to have known how they made their observations, whereas he would probably have the exact details of the practices of the Greek astronomers readily available to him. It is also possible that he believed that his readers might have more faith in Greek observations than those made in a foreign, and now deserted, city. In retrospect, given that the early Greek timings contain a systematic error, this might appear to us to be a mistake, but in the context of the *Almagest*, where they served as examples of Ptolemy's methods, they undoubtedly successfully fulfilled this role.

Chapter 4

The Near East (c. AD 820 – 1020)

Intellects are in agreement and minds are in accord as to the excellence of science and the worthiness of scientists. Through science happiness is obtained and ranks are elevated; it sharpens the intellect and strengthens it; it increases sagacity and augments perspicuity. It is by it that the indolent is embellished and the obscure is rendered illustrious, and it is with its help that the true is distinguished from the false.

— Muayyad al-Dīn al-'Urḍī, *Kitāb al-Hay'a*, c. AD 1250; translated by A. Sayili (1960)

4.1 Introduction

Some seven centuries after the demise of Mesopotamian astronomy there came a renewed interest in science and learning in the Near East.[1] Shortly after the death of the Prophet Muḥammad in AD 632, the Muslims had established a commonwealth which stretched from their heartland of western Asia east as far as India and west to Morocco and Spain. According to King (1996: 146), "it was not Islam that encouraged the development of astronomy but the richness of Islamic society, a multiracial, highly-literate, tolerant society with one predominant cultural language, Arabic." Nevertheless, Islam certainly did not oppose the development of astronomy, for it had many applications in religious practice.[2] In this chapter I will confine myself to discussing the Western Asiatic and North African areas where Islamic astronomers worked; the achievements of the Islamic astronomers in Spain will be discussed in Chapter 5 below.

Little is known of the astronomy of the Near Eastern region in the pre-Hijrah period. By about AD 800, however, foreign, predominantly Greek, science and learning became greatly sought after in Islamic society. Many Arabic translations of Greek works were made at a time when they were being lost in Europe. Although there were some tensions between foreign learning and Islam, particularly in the field of astrology, the mathematical sciences such as astronomy were strongly encouraged so long as they did not infringe on theological questions. By the thirteenth century AD Islamic science had progressed far beyond the learning of Greek methods, in which the Islamic scientists had identified many internal inconsistencies, into making many important discoveries of its own (Saliba 1982).

Given the vast number of Islamic astronomical manuscripts,[3] it is surprising how few records of astronomical observations are known. Less than fifty records of eclipses made by Islamic astronomers have been preserved. All of these date from the ninth to the eleventh centuries AD, and were observed by only six different people: Ḥabash, al-Māhānī, al-Battānī, Banū Amājūr, Ibn Yūnus and al-Bīrūnī. Many of these observations are contained in the writings of Ibn Yūnus. These have previously been used by Newcomb (1878) and Newton (1972) in an attempt to determine the secular accelerations

[1] By Near East I am referring to the Arab Lands of Asia and North Africa.

[2] For example, in constructing the lunar calendar, in determining the times of prayer, and in determining the *qibla*, the sacred direction towards Mecca which prayers and other ritual acts must be made facing.

[3] King (1996) estimates that there are over 10,000 in libraries throughout the world.

of the Sun and Moon; however, these authors based their investigation of translations which contain a number of errors. Recently, Said & Stephenson (1997) have made a detailed search for eclipse observations by Islamic astronomers. Their translations will form the basis of the present study. I shall begin this chapter by outlining the various sources of astronomical records in Near Eastern history, and then consider the eclipse observations made by each of the six astronomers mentioned above. Many of these observations also include predicted details of the eclipses, and so in the final section of this chapter, I will discuss the accuracy of all of the observed and predicted times.

4.2 Sources of Astronomical Records in Near Eastern History

Near Eastern astronomical records can be found in two main sources: historical chronicles and astronomical treatises. The latter of these two sources will form the basis for the present investigation as, although a wide variety of celestial observations are reported by various chroniclers,[4] these accounts generally lack technical details. There are many thousands of manuscripts preserved in collections throughout the world that contain the writings of medieval Islamic astronomers. These include general astronomical and cosmological discussions, commentaries on works such as the *Almagest*, and, perhaps most importantly, a group of texts known as *zījes*.

According to Kennedy (1956), who published a survey of the 125 or so *zījes* then known, a *zīj* "consists essentially of the numerical tables and accompanying explanation sufficient to enable the practicing astronomer, or astrologer, to solve all of the standard problems of his profession." In other words, the *zījes* contain the necessary tables for calculating planetary and stellar positions and eclipses, and for the measurement of time. Sometimes, but not always, the *zījes* contain explanations of the theories that they present and details of the observations on which the tables were based. Although the number of known *zījes* has increased to nearly 200 since Kennedy's survey (King 1996), nothing has been uncovered to significantly change his findings. It should be noted at this point that in many cases all that is known of a *zīj* is its title. Furthermore, there are only minor differences in the contents of many of the extant examples (King 1996).

The astronomy of the *zījes* is largely based upon that of Ptolemy. However, by the eighth century AD it had became evident to the Islamic astronomers that there were errors in some of Ptolemy's parameters. It was in an attempt to correct these errors that astronomers compiled their *zījes*, which, in some cases, necessitated the making of careful celestial observations. This is explained by the ninth century Baghdadi astronomer Ḥabash in the introduction to his *Damascus Zīj*:

> "... the astronomers of ancient times, who established the principles of this science, have left nothing for their successors to do with the exception of improvements of exposition, arrangement of material so as to facilitate understanding, correction of certain mistakes on the basis of examples of procedure available in their own texts, or the rectification of errors which were introduced after their own time."
>
> [*Damascus Zīj*, 144–145; trans. Sayili (1960: 80)]

However, it was realized, by some astronomers at least, that it was not possible to make sufficiently accurate observations to obtain a perfect theory of the heavenly motions. Ghiyāth al-Dīn explains:

> "The ascertainment with accuracy of the mean positions and the equations (of motion), and likewise, of the configurations in latitude and other matters concerning stellar bodies is humanly impossible; it is possible, nevertheless, to try to attain to the maximum precision so as not to allow any approximations in calculations to cause additional divergences exceeding observable quantities."
>
> [*Zīj-i Khāqānī fī Takmīl-i Zīj-i Ilkhānī fī'n-Nujūm*, 1; trans. Sayili (1960: 81)]

[4] Including more than one hundred solar and lunar eclipses (Said, Stephenson, & Rada 1989; Stephenson & Said 1997).

The first organized program of Islamic astronomical observations was instigated by the Abbasid Caliph al-Ma'mūn during the first part of the ninth century AD. First in Baghdad and later in Damascus, al-Ma'mūn built two observatories in which he gathered groups of astronomers (Sayili 1960). They were charged with making observations of the Sun and Moon, for, according to Ḥabash, it was in the calculation of eclipses that Ptolemy's tables showed the greatest signs of needing to be updated. Some of the results from the observations made in Baghdad were incorporated into the *al-Mumtaḥan zīj* by Yaḥyā ibn Abī Manṣūr (King 1996).

In the two centuries following al-Ma'mūn's death, astronomical research tended to be undertaken by private individuals rather than under royal patronage. Some of these individuals set up small private observatories; others worked alone, observing from a variety of different sites. Nevertheless, many *zīj*es were compiled in these centuries by such noted astronomers as al-Bāttānī, the Banū Mūsā,[5] and Ibn Yūnus. One royal observatory was built, however. This was constructed in AD 988 by Sharaf al-Dawla in the garden of his royal residence in Baghdad. Unlike al-Ma'mūn's observatories, this institution was charged with observing not only the Sun and Moon, but also the five planets. Furthermore, the Sharaf al-Dawla's observational programme was expected to continue for at least 30 years. However, it is not clear if this was achieved, for, with the exception of the observatory's inaugural observations which are reported by Ibn al-Qifṭī, very little is known about its activities.

In the latter half of the eleventh century AD, royal observatories were set up by Malikshāh and al-Afḍal al-Baṭāihī. These two institutions were to act as the forerunner for the famous Marāgha Observatory. For the first time these royal observatories were to have a significant lifetime, and were able to conduct the 30 years worth of observations stated by Sharaf al-Dawla to be essential to make significant improvements in the compilation of *zīj*es. Furthermore, the observatories now began to become not only a place to make observations and to compile *zīj*es, but also centres of learning with large library collections (Sayili 1960). The Marāgha Observatory probably represents the zenith of astronomical research in the medieval Near East. It was built around AD 1260 and was used for about fifty years; a considerable length of time as most Islamic observatories were very short lived. Saliba (1983) has uncovered a manuscript containing observational notes kept by an astronomer at the Marāgha Observatory. Other than some of the *zīj*es, this is the only manuscript known to contain observational material from this period. Unfortunately, only parts of the manuscript have as yet been studied in detail (Saliba 1985).

Before continuing to discuss the records of eclipse observations made by astronomers in the medieval Near East, it is necessary to outline the Islamic calendar and its relation to the Julian calendar. The Islamic calendar is a strictly lunar calendar — no attempt is made to reconcile the lunar months with the solar year by the use of intercalation. The year consists of twelve months each of which begin with the first sighting of the lunar crescent after the new Moon. At all major population centres a watch is kept on the 29th day of every month for the lunar crescent. If it is not seen, for example on account of bad weather, then an extra day is added to that month. Thus months in the Islamic calendar, like those in the Babylonian calendar discussed in Section 2.3 above, can have either 29 or 30 days. Due to the unpredictability of the sighting of the lunar crescent, it is difficult to calculate the exact details of the Islamic calendar in the past. Thus, to simplify conversion between the Islamic calendar and the western calendar, an idealised Islamic calendar has been devised. In this system, the first eleven months of the year contain alternatively 30 and 29 days each. The final month contains 29 days in most years, but 30 days in leap years.

Years in the Islamic calendar are numbered from the year that the Prophet Muḥammad migrated from Mecca to Medina. This event, called the Hijrah, occurred in AD 622. Years reckoned from this epoch are designated *al-Hijrah*, which has been latinized to Anno Hegirae (AH). Freeman-Grenville (1977) has constructed tables which allow dates given in the Islamic calendar to be converted to the Julian calendar with relative ease. As these tables are based upon the idealized calendar discussed

[5] *Banū* may be literally translated as "sons of" and is used as a title for a group of people. In this case these are Muḥammad Mūsā and his brother Aḥmad Mūsā.

above, errors of a day are possible in the converting from the Islamic to the Julian calendar. However, for the astronomical records these can generally be eliminated as the astronomers often recorded not only the date of an observation, but also on which of the seven days of the week it was made.

Occasionally, the Islamic astronomers recorded the date of their observations in other calendars. For example, al-Bīrūnī used a hybrid system in which the day and month were given on the Persian calendar and the year was given from the era of Nabonassar. For details of the use and operation of these calendar systems, see Said & Stephenson (1996).

4.3 Timed Eclipse Records in Near Eastern History

Timed eclipse records are preserved only in the writings of three Islamic astronomers: al-Battānī, Ibn Yūnus and al-Bīrūnī. All three men describe a number of eclipses that they observed, and, in addition, Ibn Yūnus quotes a number of eclipses that were observed by three earlier astronomers: Ḥabash, al-Māhānī and the Banū Amājūr. Despite the fact that many other astronomers, particularly those based in the observatories, are known to have observed eclipses, no other records are extant. For example, the late fourteenth century Damascene astronomer Ibn al-Shāṭir is known to have written a book entitled *Ta'līq al-Arṣād* which contained details of how he derived an alternative planetary model to that of Ptolemy from his observations. It seems that a number of eclipse observations were contained in this work. However, all manuscript copies of it have been lost (Saliba 1987).

The Islamic astronomers had two main motives in observing eclipses: testing the accuracy of planetary tables and determining geographical longitudes. All of the *zīj*es contained tables for predicting eclipses, and, by testing these tables, it was possible to assess the accuracy of the lunar theory upon which they were based. The astronomy of the *zīj*es was largely that of Ptolemy, but a number of modifications to the values of his parameters were included. With the exception of Ḥabash, all of the astronomers from whom eclipse observations are preserved made a comparison with the circumstances of the eclipses calculated by means of a *zīj* in some of their records.

The use of simultaneous observations to calculate geographical longitudes has been known since antiquity. For example, Strabo quotes Hipparchus as noting that this was the only method by which longitudes could be determined:

> "Many have testified to the amount of knowledge which this subject (Geography) requires, and Hipparchus, in his Strictures on Eratosthenes, well observes, 'that no one can become really proficient in geography, either as a private individual or as a professor, without an acquaintance with astronomy, and a knowledge of eclipses ... the only means we possess of becoming acquainted with the longitudes of different places is afforded by the eclipses of the Sun and Moon.' Such are the very words of Hipparchus."
>
> [*Geographica*, I, 1, 12; trans. Hamilton & Falconer (1903: 13)]

It does not appear that there was a sufficiently well organized system of astronomical observation in antiquity for this method to have been of widespread use (Neugebauer 1975). However, it is possible that the comparison of simultaneous observations of lunar eclipses in Babylon and Greece to determine the difference in longitude of these two cities may have been one of the motivations behind Hipparchus' compilation of historical eclipse observations.[6]

In his book on positional geography, the *Kitāb Taḥdīd Nihāyāt al-Amākin Litaṣḥīḥ Masāfāt al-Masākin*, al-Bīrūnī also discusses the use of lunar eclipses to determine differences in longitude:

> "(So) then (we consider) the eclipses of the two luminaries: With regard to the Sun, since its eclipse does not affect the Sun itself but affects the eyes of those beholding it, and since the Moon intercepting it is far away from it and is nearer to the beholders, and since, from their different localities, they make different estimates of the size of an eclipse, its duration, and the end of

[6] See Section 3.2 above.

its visibility, the solar eclipse has not been relied upon for this investigation. The eclipse of the Moon was sought, where the Sun's light which falls on it is intercepted by the Earth, occupying a position between them. It is known that it is a phenomenon which affects the Moon itself, and that beholders from different localities see it truly as it is, and at its time ... Then I say: If we know beforehand of the formation of a lunar eclipse and we wish to determine the longitudinal difference between two towns, we make arrangements beforehand for someone in each town who can measure the times accurately by instruments, to obtain as accurately as possible the times of the beginning of the eclipse and its end (i.e., its maximum phase), and those of the beginning of clearance and its end."

[*Kitāb Taḥdīd Nihāyāt al-Amākin Litaṣḥīḥ Masāfāt al-Masākin*, 166–168; trans. Ali (1967: 129–130)]

Al-Bīrūnī then proceeds to discuss the exact methods by which the difference in longitude between two observational sites may be derived from the lunar eclipse observations. He also gives some account of the problems encountered in observing eclipses:

"An eclipse (of the Moon) does not become clear to the beholder until the portion formed of it, according to some authors of *zījes*, amounts to one digit, I mean a part one twelfth of its size. Also, a limit has been set to its time; in time units it is 1;48°, and in hours it is 0;6,16. By this amount of time the beginning of the true eclipse precedes the apparent beginning, and the completion of this true clearance succeeds the apparent clearance. The author of this statement may have said so about both of them, but that is subject to enquiry and examination. I consider the amount of a digit in this connection to be excessive, because a small immersion can be seen, though the first contact between the shadow and the Moon is imperceptible."

[*Kitāb Taḥdīd Nihāyāt al-Amākin Litaṣḥīḥ Masāfāt al-Masākin*, 168; trans. Ali (1967: 130–131)]

Obviously, there was no consensus between the various astronomers on the delay between the true and the apparent beginning of a lunar eclipse. Ibn Yūnus occasionally notes both the time when the eclipse was perceived to begin and his estimate of the true time of first contact. However, in most cases no distinction between these two times is made. Hence, as it is impossible to determine the delay in perceiving the beginning of the eclipse since it is a physiological factor dependent on the eye of the observer, I assume that the quoted times relate to the moment of true first contact.

It would appear that the Islamic astronomers observed solar eclipses by looking at the Sun's reflected image in a pool of water. Al-Bīrūnī writes:

"It (observing the Moon) is unlike (observing) the Sun because the faculty of sight cannot resist its (i.e., the Sun's) rays, which can inflict a painful injury. If one continues to look at it, one's sight becomes dazzled and dimmed, so it is preferable to look at its image in water and avoid a direct look at it, because the intensity of rays is thereby reduced and one can look at its disc. Indeed, such observations of solar eclipses in my youth have weakened my sight ..."

[*Kitāb Taḥdīd Nihāyāt al-Amākin Litaṣḥīḥ Masāfāt al-Masākin*, 168–169; trans. Ali (1967: 131)]

Similar remarks about observing the Sun by reflection in water are made by Banū Amājūr in the report of the eclipse on the 18th August 928 AD. Of course, no such precautions needed to be taken when observing lunar eclipses.

The Islamic astronomers appear to have determined the time of an eclipse by measuring the altitude of either a clock-star or of the eclipsed luminary. In many of the eclipse records the original altitude measurements are reported. Sometimes, the reports contain the local time deduced from these altitudes. Stephenson & Said (1991) have shown that this reduction was usually done with considerable accuracy. Other reports only contain the reduced local time. Both equinoctial and, following ancient Greek practice, seasonal hours are used. Although simple water-clocks were used in the Near East from an early period, it seems that it was not until the eleventh century AD that any significant attempts were made to build a highly accurate device (Al-Hassan & Hill 1986: 55–59). Furthermore, the earliest evidence for the use of a water-clock by an astronomer comes from the

City	Latitude (o)	Longitude (o)
al-Raqqah	35.94	-39.02
Anṭākyah	36.20	-36.17
Baghdad	33.34	-44.40
Cairo	30.05	-31.25
Ghaznah	33.55	-68.43
Jurjān	36.83	-54.48
Jurjāniyyah	42.30	59.16
Nīshāpūr	36.21	58.83

Table 4.1: Near Eastern observation sites.

thirteenth century AD when Maghribī used one at the Marāgha Observatory (Saliba 1986). Thus it seems clear that water-clocks played no part in the timing of eclipses by Islamic astronomers.

The instrument used to measure altitudes during the observed eclipses is hardly ever mentioned, but it was in all likelihood a hand-held astrolabe. This device functioned both as an instrument for measuring altitudes and as a analogue computer for converting altitudes into local times.[7] Alternatively, tables have been found that enable altitude measurements to be converted to local times (Goldstein 1963; King 1973), but it is not clear how often these were used.

In the following sections I will discuss the eclipse observations made by Ḥabash, al-Māhānī, al-Battānī, Banū Amājūr, Ibn Yūnus and al-Bīrūnī in turn. In doing so I will make use of the translations of these observations by Said & Stephenson (1997). They have corrected a number of scribal errors in the texts which I have, on the whole, accepted without comment. Ḥabash, al-Māhānī, and Banū Amājūr, made their observations from Baghdad, Ibn Yūnus made his from Cairo, al-Battānī from al-Raqqah and Anṭākyah, and al-Bīrūnī and his colleagues made their observations from Nīshāpūr, Jurjān, Jurjāniyyah, and Ghaznah. The latitudes and longitudes of these sites are given in Table 4.1. It should be noted that, with the exception of Cairo (Arabic: al-Qāhirah), I have used the original Arabic names for these cities.

4.3.1 Ḥabash

Ḥabash al-Ḥāsib worked in Baghdad during the first half of the ninth century AD. In addition to making numerous observations, he compiled several important *zījes*, including the *Damascus Zīj* and the *Mumtaḥan Zīj*. These both rely heavily on Ptolemy, but were based upon Ḥabash's own observations (Kennedy 1956). Ḥabash also wrote on the construction of astrolabes and other astronomical instruments, and made important contributions in the field of trigonometry.[8]

Two observations of eclipses by Ḥabash in AD 829 are reported by Ibn Yūnus in his *al-Zīj al-Kabīr al-Ḥākimī*:

> "Aḥmad b. 'Abd Allāh known as Ḥabash said: 'There was a lunar eclipse after Nowrūz (i.e., the Persian word for a new day which is the first day of a new year) in the year 198 of Yazdijerd. (The prediction of the) calculations of (*al-Zīj*) al-Mumtaḥan and of Ptolemy were near to each other ... As for the solar eclipse, which (occurred) in this year at the end of the month of Ramaḍān, all calculations (concerning the eclipse) were in error. The altitude of the Sun at the beginning was 7° as they (the astronomers) claim. The eclipse ended when the altitude of the Sun was about 24°, as though it was 3 (seasonal) hours of day (i.e., after sunrise)'."
>
> [*al-Zīj al-Kabīr al-Ḥākimī*; trans. Said & Stephenson (1997: 30)]

[7]For a detailed explanation of the construction and use of an astrolabe, see North (1974). Of the many treatises on the astrolabe by Islamic astronomers the most detailed is by al-Ṣūfi. See Kennedy & Destombes (1966) for a commentary on this text. For a preliminary survey of known astrolabes and their makers, see Mayer (1956). He concludes that most astrolabes were built by the astronomer who intended to use it.

[8]For further biographical details, see Tekeli (1972)

				Altitude (°)			Local Time (h)	
Date	Type	Contact	Object	Observed	Computed	Predicted	Observed	Computed
829 Nov 30	Solar	1	Sun	7.00	1.63	-	7.68	7.07
		4	Sun	24.00	22.82	-	9.49	9.35

Table 4.2: Eclipse observation made by Ḥabash.

Unfortunately, no details of the lunar eclipse observation are given. However, the altitude of the Sun at both the beginning and end of the solar eclipse, and the reduced time of its end are reported. This eclipse occurred on the 30th November 829 AD.

The measured altitudes and times of the eclipse observed by Ḥabash are shown in Table 4.2. For comparison, the values given by modern computations are also given. Clearly, there is a considerable error in the measured altitude of the Sun when the eclipse began. The cause of this error is not known. It may have been due to a delay by Ḥabash in noticing the beginning of the eclipse; since the Sun was rising higher in the sky during the eclipse, this would have resulted in a measured altitude that was too great.

As there is only one record of a timed eclipse observation by Ḥabash preserved it is not possible to make a reliable estimate of the typical accuracy of his eclipse timings. However, the mean accuracy of these two timings is about 0.38 hours.

4.3.2 al-Māhānī

Al-Māhānī worked on various problems of astronomy and mathematics during the latter half of the ninth century AD. Based in Baghdad, his main achievements were in mathematics where he wrote, among other works, a commentary on parts of Euclid's *Elements*. Between AD 854 and AD 866 al-Māhānī observed three lunar and one solar eclipse. These, together with a number of conjunctions, are reported by Ibn Yūnus in his *al-Zīj al-Kabīr al-Ḥākimī*. It seems likely that al-Māhānī may have made many further observations, but no source has as yet been found to contain them.[9]

The record of the lunar eclipse on the 12th August 854 AD is interesting as al-Māhānī notes that his altitude measurements were converted to local times by the use of an astrolabe:

> "This lunar eclipse was mentioned by al-Māhānī. 'The Moon was eclipsed on the night of Sunday 13th of the month of Rabī 'al-Awwal in the year 240 of al-Hijrah. It was found by observation that the time of the beginning of the eclipse was when the altitude of (the star) *al-dabarān* (Aldebaran: α Tau) was 45;30° in the east. We did not find its times (accurately) except this time (i.e., of the beginning), which was exact and precise. We measured the time of the completion of (the first phase of) the eclipse, which is the time of the beginning of the staying (Arabic: *al-makth*) (in totality) and found it (to be) when the altitude of (the star *al-shi'rā*) *al-shāmiyyah* (Procyon: α CMi) was between 22° and 23° in the east. This (latter) measurement is not exact but approximate. We determined the time of the beginning from the altitude of *al-dabarān* by the astrolabe and found it to be 44° (of the celestial sphere) after midnight. The time of beginning was 8° later than its (calculated) time. We (also) determined the time (of the beginning of) the stay by the astrolabe, taking the altitude of (*al-shi'rā*) *al-shāmiyyah* as 23° and found it to be $23\frac{1}{2}$ parts (i.e., degrees) of the celestial sphere after the (time of the) beginning (of the eclipse)'."
>
> [*al-Zīj al-Kabīr al-Ḥākimī*; trans. Said & Stephenson (1997: 31)]

As Stephenson & Said (1991) have shown, al-Māhānī reduced his altitude measurements to local times with a high degree of accuracy. In this example, the error in his two reductions is less than 3 minutes of time. Indeed, for the error in the reduction of the altitude of α Tau to the local time is less than half a minute.

[9] For further biographical details, see Dold-Samplonius (1974).

				Altitude (°)			Local Time (h)	
Date	Type	Contact	Object	Observed	Computed	Predicted	Observed	Computed
854 Feb 16	Lunar	1	-	-	-	-	22.05	22.21
854 Aug 12	Lunar	1	α Tau	45.50	45.32	2.40	2.93	2.91
		2	α CMi	23.00	18.30	-	4.50	4.11
856 Jun 21	Lunar	1	α Tau	9.50	8.02	2.83	3.33	3.33
866 Jun 16	Solar	1	-	-	-	12.06	12.33	12.37
		M	-	-	-	13.40	13.72	13.73
		4	-	-	-	14.72	15.00	14.98

Table 4.3: Eclipse observations made by al-Māhānī.

In recording many of his eclipse observations, including the example quoted above, al-Māhānī compared his observed local times with those calculated by means of tables. Unfortunately it is not known which set of tables al-Māhānī used, but it is unlikely to have been those of his own *zīj*. According to Kennedy (1956) this *zīj* is not extant, but is known only from the writings of al-Fārisī who said that it was compiled by al-Māhānī in about AD 860. As most of al-Māhānī's eclipse observations are earlier than this it seems likely that these observations were among those that he used to compile his *zīj*.

Table 4.3 summarizes al-Māhānī's eclipse observations and predictions. The mean accuracy of the observed times is about 0.09 hours and there is no evidence for any systematic error in the times. For the predicted times, the true accuracy, by which I mean the accuracy of the predicted time as compared with modern computation, is about 0.38 hours. The observed accuracy of the predicted times, by which I mean the accuracy when compared with al-Māhānī's observations, is also about 0.38 hours. The accuracy of the predicted times of the solar eclipse on the 16th June 866 AD is slightly better than those of the earlier lunar eclipses. This may suggest that al-Māhānī used his newly compiled *zīj* to make this prediction, but as there are so few eclipses it is not possible to draw any firm conclusions in this regard.

4.3.3 al-Battānī

Al-Battānī is one of the most noted of all Islamic astronomers. He was born in AD 858 in the city of Ḥarrān, but spent most of his working life in the city of al-Raqqah. According to Ibn al-Qifṭī, a thirteenth century AD biographer, al-Battānī was "one of the illustrious observers and foremost in geometry, theoretical and practical astronomy, and astrology."[10] In about AD 900 al-Battānī compiled his *zīj* entitled the *Az-zīj aṣ-Ṣabi'*. This *zīj* was one of the most important compiled by an Islamic astronomers. It was largely based on the astronomy of Ptolemy, but showed a considerable improvement over his parameters (Kennedy 1956).[11]

From AD 887 al-Battānī made over forty years worth of observations from his observatory at al-Raqqah. This observatory, built by al-Battānī with his own money, was well equipped with astrolabes, a gnomon, a large parallactic ruler, and a mural quadrant with a radius of over one meter. In his *zīj*, al-Battānī reports observations of four eclipses. The first two he observed from his observatory in al-Raqqah for the purpose of investigating the accuracy of Ptolemy's tables. In AD 901, however, he travelled to Anṭakya to observe two eclipses. He arranged for a colleague to observe the same two eclipses from al-Raqqah so that he could attempt to determine the difference in longitude between the two cities. I quote below a translation of his accounts of the solar eclipse on the 23rd June 901 AD:

> "This solar eclipse was observed by us at the city of Anṭakya on the 23rd of (the month of) Kānūn al-Thānī in the year 1212 of *Dhū al-Qarnayn* (i.e., Alexander IV), which is the year 1224 after

[10] *Ta'rīkh al-Ḥukamā'*; trans. Hartner (1970: 507–508).

[11] For further biographical details, see Hartner (1970).

Date	Type	Contact	Object	Altitude (°) Observed	Computed	Local Time (h) Predicted	Observed	Computed
883 Jul 23	Lunar	M	-	-	-	19.25	20.00	19.70
891 Aug 8	Solar	M	-	-	-	12.00	13.14	12.89
901 Jan 23	Solar	M[1]	-	-	-	-	8.33	8.12
		M[2]	-	-	-	10.50	8.50	8.37
901 Aug 2	Lunar	M[1]	-	-	-	-	3.33	2.86
		M[2]	-	-	-	-	3.58	3.08

1. Observed by al-Battānī in Anṭakya.
2. Observed for al-Battānī in al-Raqqah.

Table 4.4: Eclipse observations made by al-Battānī.

the death of al-Iskandar (i.e., Alexander III, the Great). The middle of the eclipse was about $3\frac{2}{3}$ equal hours before midday. (A little) more than $\frac{1}{2}$ of the Sun (i.e., Sun's surface) in sight was eclipsed. In this eclipse the Sun was at its nearest distance (perigee) and the Moon was nearly at its middle distance ... This (same) eclipse was observed by someone on our behalf at the city of al-Raqqah. The middle of the eclipse was (a little) less than $3\frac{1}{2}$ equal hours before midday. A little less than $\frac{2}{3}$ of the Sun in view was eclipsed. According to calculation from Ptolemy('s tables), the Sun should have been totally eclipsed, and the (time of) the middle of the eclipse was later than the observed time by about two hours. Such a discrepancy is not acceptable."

[*Az-zīj aṣ-Ṣabi'*; trans. Said & Stephenson (1997: 43–44)]

Al-Battānī's eclipse records are summarized in Table 4.4. The mean accuracy of his observed times in about 0.31 hours. Furthermore, all of his times are late; however, there are too few observations to conclude that his timing methods suffered from a systematic error. The accuracy of the times predicted with Ptolemy's tables is also very poor — the true accuracy is about 1.16 hours and the observed accuracy is about 1.30 hours. In light of this, al-Battānī's remark that Ptolemy's tables are "not acceptable" appears to be fully justified.

4.3.4 Banū Amājūr

Banū Amājūr is the name given to a group of astronomers who observed in Baghdad, and possibly also Shiraz, between AD 885 and AD 933. The group consisted of Abū al-Qāsim 'Abd Allāh ibn Amājūr, his son Abū al-Ḥasan 'Alī ibn Amājūr, and their freed slave Mufliḥ ibn Yūsuf. It is possible that others, in particular a third member of the Amājūr family, may have collaborated with them on occasions (Sayili 1960: 101–103). In addition to their extensive observational programme, the Banū Amājūr compiled five *zīj*es, none of which is extant (Kennedy 1956).

Ibn Yūnus reports observations of a number of observations of eclipses made by the Banū Amājūr between AD 923 and AD 933. The record of the solar eclipse on the 11th November 923 AD gives some details of the site in Baghdad from which they made their observations:

"This solar eclipse was calculated and observed by Abū al-Ḥasan 'Alī ibn Amājūr from *al-Zīj al-'Arabī* of Ḥabash. This eclipse was at the conjunction (i.e., new Moon) of (the month of) Sha'bān in the year 311 (AH). We as a group observed (this eclipse) and clearly distinguished it. The estimate of all (observers) for the middle of the eclipse was that is occurred when the altitude of the Sun was 8° in the east; its clearance was at $2\frac{1}{5}$ seasonal hours (after sunrise), when the altitude of the Sun was 20°. We observed this eclipse at several sites on the 'Ṭārmah'. The estimate of Abū al-Ḥasan for the middle of the eclipse at his house was when the altitude of the Sun was 8°, as I estimated myself at my house before he arrived. The magnitude of the eclipse was $\frac{1}{2}$ and $\frac{1}{4}$ (i.e., $\frac{3}{4}$) of the Sun's diameter; the middle of the eclipse, which we estimated when the Sun's altitude was 8°, is to be when the elapsed time (after sunrise) was 0;50 seasonal hours, and the (celestial) sphere had revolved (through) 10;40°. (The interval) between the middle of the

				Altitude (°)			Local Time (h)	
Date	Type	Contact	Object	Observed	Computed	Predicted	Observed	Computed
923 Jun 1	Lunar	M	-	-	-	-	20.80	20.57
		4	α Cyg	29.50	33.80	-	22.13	21.95
923 Nov 11	Solar	M	Sun	8.00	7.63	7.30	7.51	7.52
		4	Sun	20.00	18.72	7.52	8.70	8.55
925 Apr 11	Lunar	1	α Boo	11.00	34.04	19.07	19.39	19.53
		4	α Lyr	24.00	24.77	22.84	23.12	22.84
927 Sep 13	Lunar	1	α CMa	31.00	33.76	4.12	4.03	4.22
		M	-	-	-	5.21	-	5.04
		4	-	-	-	5.99	-	5.57
928 Aug 18	Solar	1	-	-	-	4.77	-	5.01
		M	-	-	-	5.64	-	5.67
		4	Sun	11.89	11.21	6.39	6.44	6.36
929 Jan 27	Lunar	1	α Boo	18.00	31.50	22.81	22.88	23.89
		2	-	-	-	0.43	-	1.06
		M	-	-	-	0.56	-	1.69
		3	-	-	-	0.93	-	2.12
		4	-	-	-	2.42	-	3.29
933 Nov 4	Lunar	1	α Boo	15.00	15.18	4.18	4.56	4.63
		2	-	-	-	5.43	-	5.77
		3	-	-	-	6.88	-	7.30
		4	-	-	-	8.00	-	8.43

Table 4.5: Eclipse observations made by Banū Amājūr.

eclipse and its clearance in this observation was 1;22 seasonal hours; the (corresponding) time was 1;10 equal hours because the sphere revolved (through) 28;9° at the moment of clearance, which is (equivalent to) 1;53 equal hours. The middle would be at 0;43 equal hours. According to calculation from the conjunction tables in the Ḥabash *zīj* the middle was at 0;31 hours and its clearance at 0;44 hours, calculation being in advance of observation."

[*al-Zīj al-Kabīr al-Ḥākimī*; trans. Said & Stephenson (1997: 34)]

The "Ṭārmah" referred to by Banū Amājūr is an elevated platform on the side of a building (Said & Stephenson 1997). Elsewhere it is written that this platform had certain slits in its walls indicating fixed directions. Although there is no direct evidence that this platform was specifically intended to be used for celestial observations, Sayili (1960) has suggested that this house may have been built as a private observatory by the Banū Amājūr.

At the end of the eclipse report quoted above, Banū Amājūr notes that there is a difference between their observed times and those predicted using Ḥabash's *zīj*. This appears to be the primary motivation behind the Banū Amājūr's eclipse observations. Presumably they used these and other observations to construct there own *zīj*es. Unfortunately, as these *zīj*es are lost it is not possible to find out whether they gave better agreement with observation than did those of Ḥabash.

Table 4.5 summarizes the Banū Amājūr's eclipse observations and predictions (using the tables of Ḥabash). The mean accuracy of the observed times is about 0.15 hours and there no evidence for any significant systematic error. The true accuracy of the times predicted using the tables of Ḥabash is about 0.52 hours. This is significantly poorer than the observed accuracy of these predicted times which is about 0.32 hours. This implies that the Banū Amājūr would have overestimated the accuracy of these tables in predicting eclipses.

4.3.5 Ibn Yūnus

Along with al-Battānī, Ibn Yūnus is regarded as one of the greatest astronomers of medieval Islam. He was born and worked in Egypt during the latter half of the tenth and the former half of the eleventh centuries AD. Between AD 977 and AD 1004 he made astronomical observations for the Caliph al-'Azīz and his successor, the young Caliph al-Ḥākim. These observations were made in Cairo at

Date	Type	Contact	Object	Altitude (°) Observed	Computed	Predicted	Local Time (h) Observed	Computed
977 Dec 13	Solar	1	Sun	15.50	15.79	-	8.40	8.42
		4	Sun	33.33	33.80	-	10.71	10.79
978 Jun 8	Solar	1	Sun	56.00	58.71	-	14.50	14.29
		4	Sun	26.00	24.97	-	16.83	16.91
979 May 14	Lunar	4	-	-	-	-	20.07	20.01
979 May 28	Solar	1	Sun	6.50	7.31	-	18.38	18.30
979 Nov 6	Lunar	1	Moon	64.50	65.09	-	22.41	22.45
		4	Moon	65.00	66.21	-	1.61	1.51
980 May 2	Lunar	1	Moon	40.66	40.24	-	0.84	0.93
		4	-	-	-	-	4.65	4.76
981 Apr 22	Lunar	1	Moon	21.00	19.99	-	3.53	3.63
		4	-	-	-	-	5.15	5.33
981 Oct 16	Lunar	1	Moon	24.00	24.67	4.85	4.45	4.37
983 Mar 2	Lunar	1	Moon	66.00	65.82	23.33	0.00	0.01
		4	Moon	35.83	3.50	2.75	3.42	3.28
985 Jul 20	Solar	1	Sun	23.00	26.70	-	16.95	16.68
		4	Sun	6.00	8.58	-	18.34	18.10
986 Dec 19	Lunar	1	Moon	30.50	27.06	-	4.39	4.65
990 Apr 12	Lunar	1	Moon	38.00	22.37	-	21.81	22.33
		4	-	-	-	-	1.27	1.49
993 Aug 20	Solar	1	Sun	27.00	28.57	-	7.67	7.79
		M	Sun	45.00	43.88	-	9.07	8.99
		4	Sun	60.00	59.86	-	10.34	10.32
1001 Sep 5	Lunar	1	-	-	-	-	20.17	19.87
1002 Mar 1	Lunar	1	α Boo	52.00	53.37	-	23.48	23.59
		1	α Aur	14.00	13.78	-	23.55	23.59
1004 Jan 24	Solar	1	Sun	18.50	19.05	-	15.68	15.63
		M	Sun	5.00	6.59	-	16.88	16.75

Table 4.6: Eclipse observations made by Ibn Yūnus.

a variety of sites.[12] Ibn Yūnus' major work was the *al-Zīj al-Kabīr al-Ḥākimī*, although he also compiled a set of tables for determining the time of day from solar observations (King 1973), and even works of poetry (King 1976). His *zīj* is only extant in fragments, but is known to have contained eighty-one chapters (Kennedy 1956). Parts of this *zīj* have been translated into French by Caussin (1804). The *zīj* is unique among extant examples in containing details of a number of observations made not only by Ibn Yūnus, but also by earlier astronomers such as al-Māhānī and Banū Amājūr, as discussed above.[13]

Ibn Yūnus records 16 of his own eclipse observations in his *zīj*. These were all observed in Cairo. His earliest observation, dating from 13th December 977 AD, was made from the roof of a mosque:

> "This solar eclipse was in the early morning of Thursday the 28th of the month of Rabi 'al-ākhīr, in the year 367 of al-Hijrah, which is the 22nd of the month of Ādhar in the year 346 of Yazdijerd. We, a group of scholars ... (ten names are given) attended at al-Qarāfah (a district of Cairo) in the Mosque of Abū Ja'far Aḥmad ibn Naṣr al-Maghribī to watch this eclipse. Everyone waited for the beginning of this eclipse. It began to be perceived when the altitude of the Sun was more than 15° but less than 16°. (Those) present all agreed that about 8 digits of the Sun's diameter were eclipsed, that is (a little) less than 7 digits of surface. The Sun was completely cleared when its altitude was more than 33° by about $\frac{1}{3}$ of a degree, as estimated by me, and agreed by all those present. The Sun and Moon in this eclipse were at their nearest distance (from the Earth — i.e., at perigee)."
>
> [*al-Zīj al-Kabīr al-Ḥākimī*; trans. Said & Stephenson (1997: 37)]

[12] It has often been claimed that al-Ḥākim built an observatory for Ibn Yūnus in Cairo, but Sayili (1960: 130–156) has shown this to be untrue. Instead he argues that Ibn Yūnus may have built his own private observatory in his house.

[13] For further biographical details, see King (1976).

				Altitude (°)		Local Time (h)		
Date	Type	Contact	Object	Observed	Computed	Predicted	Observed	Computed
1003 Feb 19	Lunar	M	-	-	-	-	18.73	18.70
1003 Aug 14	Lunar	M	-	-	-	-	23.60	23.35
1004 Jul 4	Lunar	M	-	-	-	-	2.61	2.90
1019 Sep 17	Lunar	1	α Aug	66.00	66.77	-	2.29	2.39
		1	α CMa	17.00	18.62	-	2.34	2.39
		1	α CMi	21.00	23.99	-	2.32	2.39
		1	α Tau	63.00	63.09	-	2.38	2.39
		4	-	-	-	4.19	-	5.59

Table 4.7: Eclipse observations made by al-Bīrūnī.

On two other occasions Ibn Yūnus states that he observed the eclipse from this Mosque; no observation site is mentioned for the other cases.

In two of his eclipse records, Ibn Yūnus compares the observed times with those calculated by means of Yaḥyā ibn Abī Manṣūr's *al-Zīj al-Mumtaḥan*, noting deviations of about half an hour. His observed and computed times are summarized in Table 4.6. The mean accuracy of his observed times is about 0.14 hours with negligible systematic error. The mean true accuracy of the predicted times is about 0.24 hours, and the mean observed accuracy of the predicted times is about 0.31 hours. However, as there are only three predicted times, it is not possible to draw any firm conclusions on the accuracy of the *al-Mumtaḥan* tables.

4.3.6 al-Bīrūnī

Al-Bīrūnī was something of a polymath. During the first half of the eleventh century AD he wrote more than 146 works, of which only 22 are extant, on subjects ranging from astronomy and geography to history and literature.[14] He travelled, both voluntarily and for political reasons, from Baghdad to various parts of India. Al-Bīrūnī's most important works related to astronomy are his *zīj*, the *al-Qānūn al-Mas'ūdī*,[15] and his *Kitāb Taḥdīd Nihāyāt al-Amākin Litaṣḥīḥ Masāfāt al-Masākin*,[16] whose main theme is the determination of geographical coordinates.[17]

Al-Bīrūnī records observations of four lunar eclipses in the two works noted above.[18] These were observed in a variety of cities: Jurjān in AD 1003, Jurjāniyyah in AD 1004, and Ghaznah in AD 1019. I quote below a translation of the first of his observations:

> "This lunar eclipse was on the night of Saturday the 14th of the month of Rabī' al-Ākhīr in the year 393 (of al-Hijrah). I observed the beginning and clearance at Jurjān by the altitude of the (two stars) *al-Shi'rayān* (i.e., *al-shi'rā al-yamāniyyah* — Sirius: α CMa — and *al-shi'rā al-shāmiyyah* — Procyon: α CMi). The Moon was eclipsed by $\frac{1}{4}$ of its diameter by estimate. The longitude difference between Jurjān and Ghaznah is 2;21 minutes of day. The middle of the eclipse at it (presumably at Ghaznah) was 10;11 (minutes of day) after midday of Friday, the 6th of the month of Isfandārmadh in the year 1751 of Bukhtinassar (i.e., Nabonassar)"
>
> [*al-Qānūn al-Mas'ūsī*; trans. Stephenson & Said (1997: 45)]

[14]For a list of al-Bīrūnī's works, including details of those that are extant, and those that have been published, see Kennedy (1970).

[15]This work is described by Kennedy (1956: 157–159).

[16]This work has been translated into English by Ali (1967).

[17]For further biographical details, see Kennedy (1970).

[18]Al-Bīrūnī also reports an observation of an annular solar eclipse by al-Irānshahrī on the 28th July 873 AD. Although no timings of this eclipse are reported, it is of considerable historical interest as according to Ptolemy (*Almagest*, V, 14) annular eclipse are not possible. See Goldstein (1979).

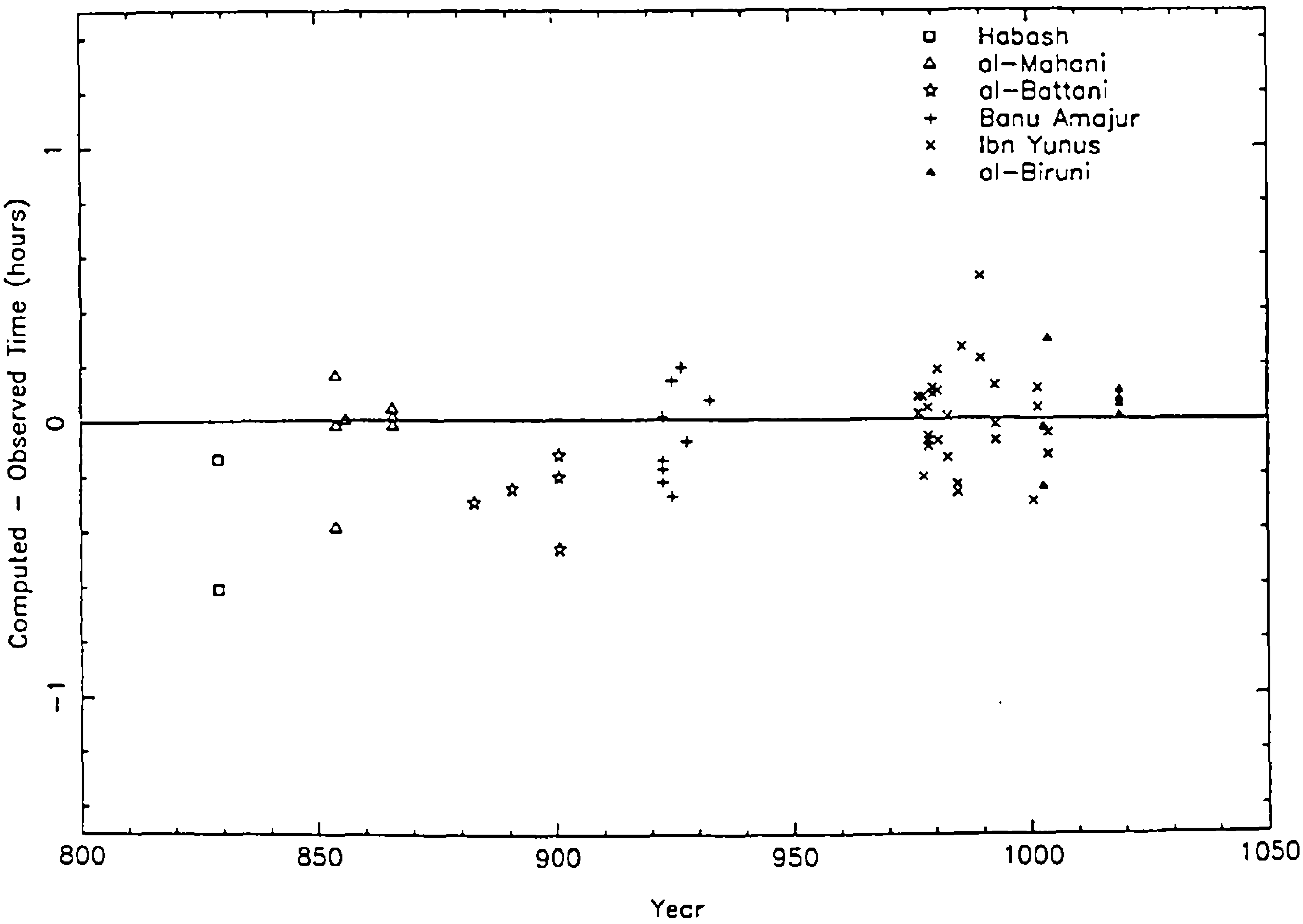


Figure 4.1: Error in the observed eclipse times.

The observed local time at Jurjā is reduced by al-Bīrūnī to Ghaznah using a longitude difference of 2;21 degrees of day, where one degree of day corresponds to $\frac{1}{60}$ of a day, or 0.4 equal hours. Al-Bīrūnī's longitude difference (0.94 hours) is very close to the modern value (0.93 hours) (Said & Stephenson 1997).

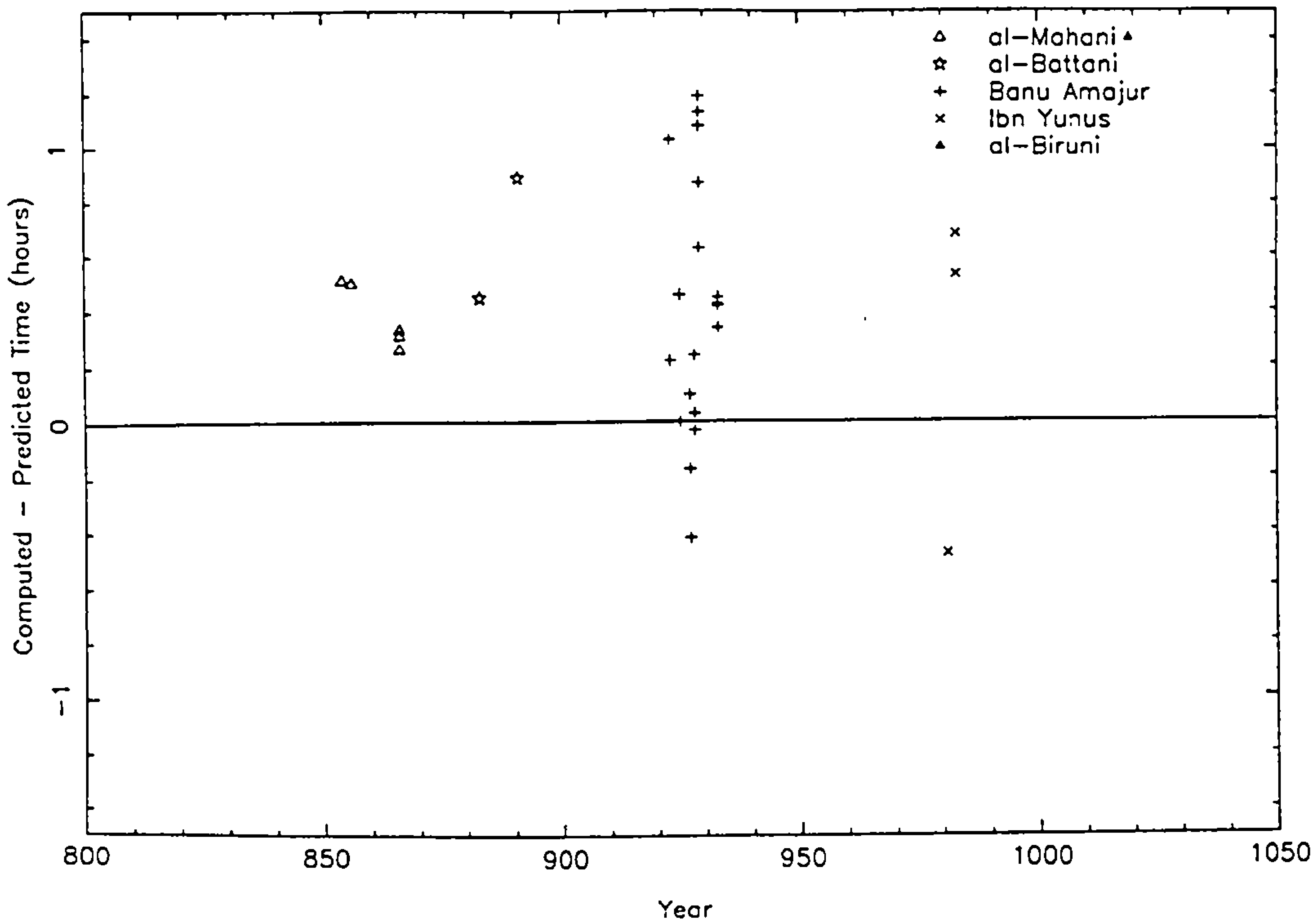
Table 4.7 summarizes al-Bīrūnī's observed eclipse times. The mean accuracy of these times is about 0.10 hours, with no significant systematic error. In reporting the eclipse on 17 September 1019 AD al-Bīrūnī notes that:

> "... some astronomers from Khurāsān predicted that the completion of the clearance would be when $10\frac{1}{4}$ hours of night had elapsed. Since night hours were then nearly equal to daytime hours, because the Sun was in the last degrees of Virgo, this would be when 1 plus $\frac{1}{2}$ plus $\frac{1}{4}$ (i.e., $1\frac{3}{4}$) hours of night remained (i.e., before sunrise). It was clear to the sight that the world was lit up, the stars had disappeared, the Sun was about to rise, and the Moon was about to set behind the mountains which screened it. A small portion of the eclipse (still) remained in its body (i.e., disk) and I was unable to observe it (i.e., the time of clearance) exactly."
>
> [*Kitāb Taḥdīd Nihāyāt al-Amākin Litaṣḥīḥ Masāfāt al-Masākin*; trans. Said & Stephenson (1997: 47)]

It is clear from Table 4.7, however, that this prediction was very inaccurate — the predicted time is 1.40 hours earlier than computed.

4.4 Accuracy of the Observed and Predicted Times

The errors in the observed times of all of the eclipses observed by medieval Islamic astronomers are shown in Figure 4.1. The typical accuracy of these observations is between about 6 and 10 minutes. As I have discussed above, the timings by Ḥabash and by al-Bāttānī are of slightly poorer accuracy



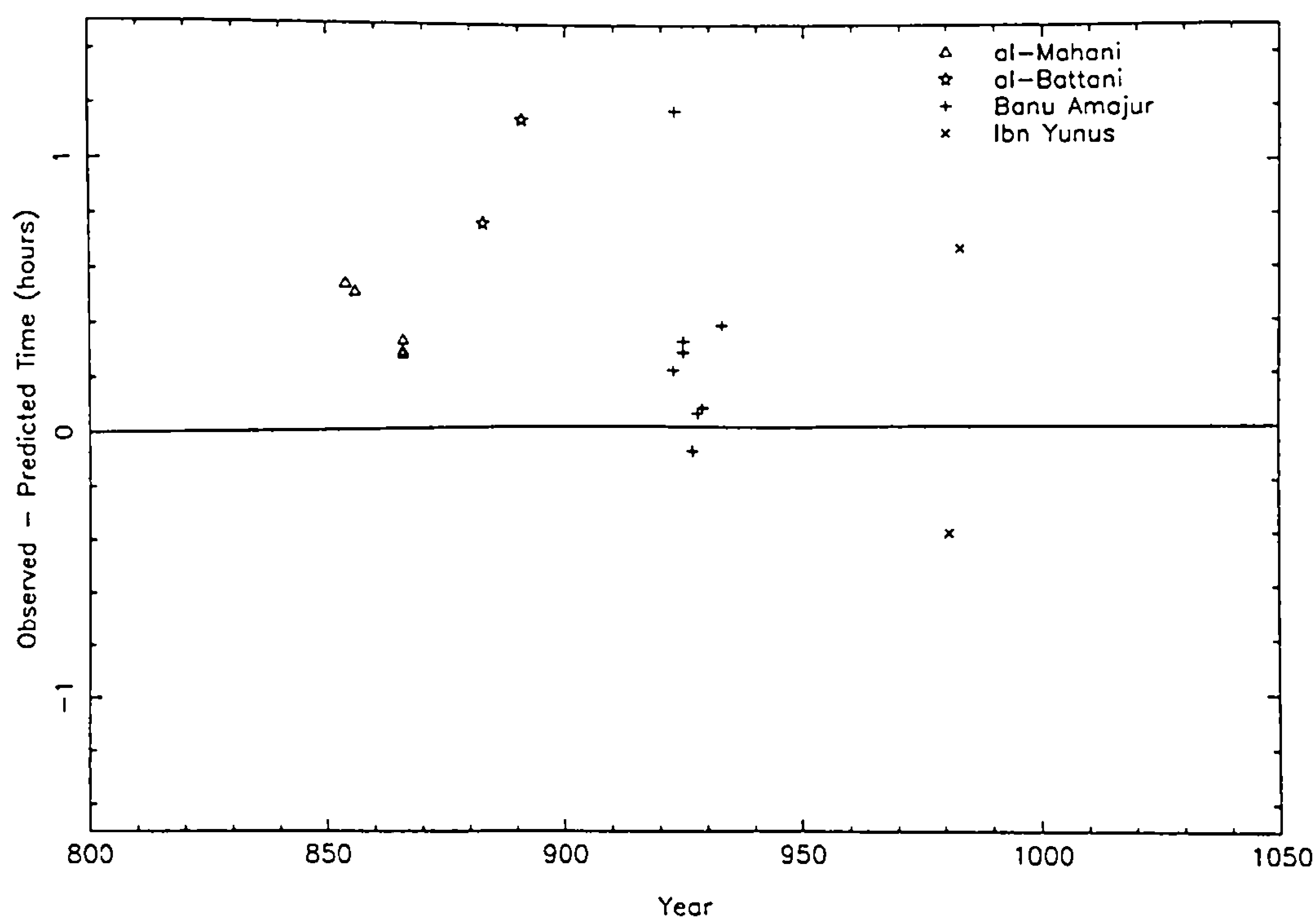


Figure 4.2: The true (above) and observed (below) error in the predicted eclipse times.

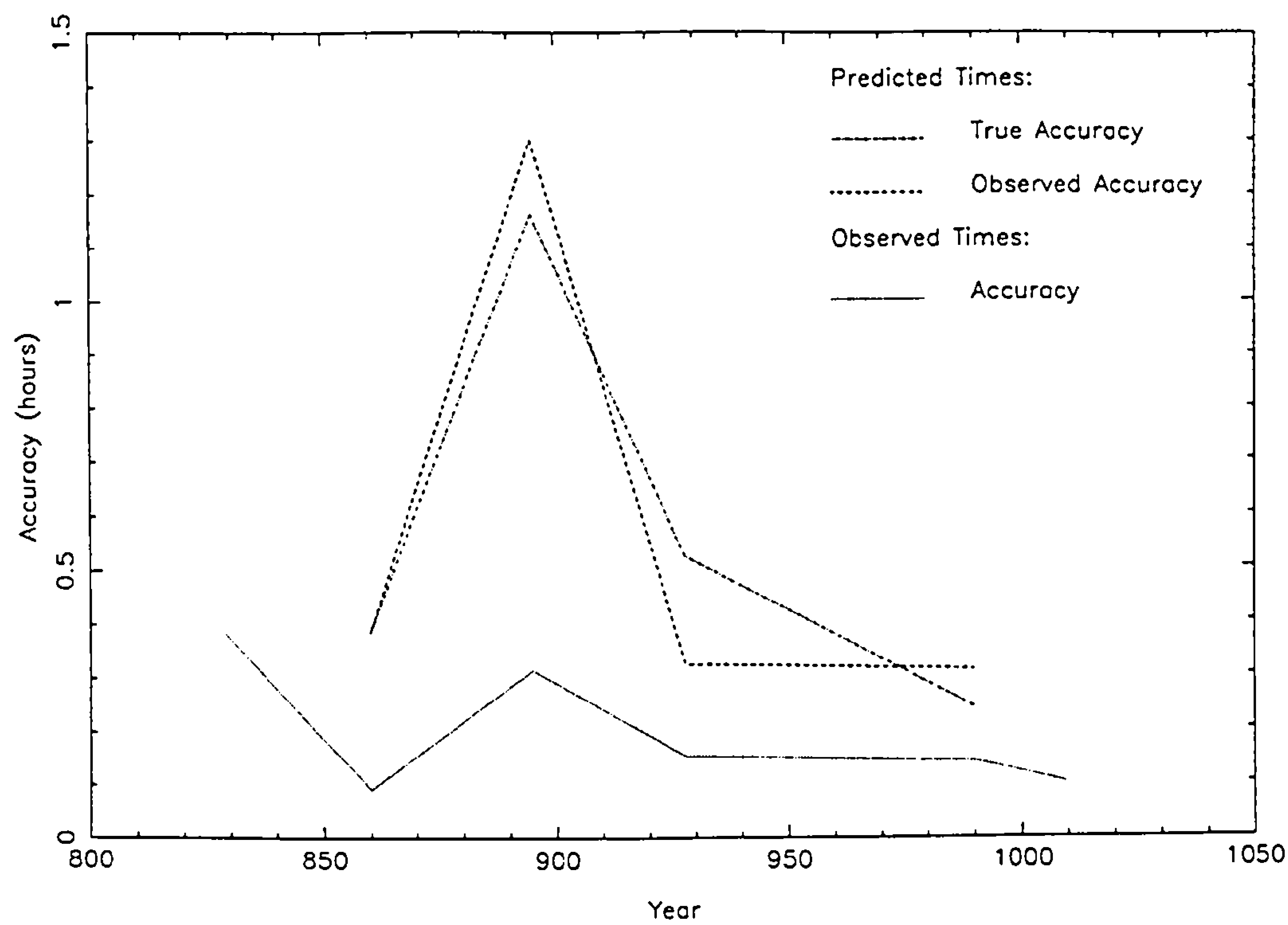


Figure 4.3: Schematic representation of the accuracy of the eclipse times.

than those of their contemporaries. This conflicts with the view expressed by Ibn al-Qifṭū that al-Bāttānī was one of the foremost observers of his age.

Figure 4.2 shows the true and observed errors in the eclipse times predicted by al-Māhānī, al-Battānī, Banū Amājūr, Ibn Yūnus and al-Bīrūnī. The prediction of the time of the maximum phase of the solar eclipse on the 23rd January 901 AD is in error by more than 2 hours, and so has not been included in the Figure. It is clear that the typical accuracy of each group of eclipse predictions is not the same. This is not surprising as they were made using different sets of tables. The accuracy of each group of predictions is shown more clearly in Figure 4.3. The lines in this figure connect points showing the mean accuracy of each set of predictions at their mean date. For reference, the accuracy of each set of observed times is also shown. It should be noted, however, that the straight lines in the Figure should not be interpreted as implying any form of linear change in accuracy between the points, but merely illustrate the general trend in the accuracy of predictions in this period. The very inaccurate prediction made by "some astronomers from Khurāsān" and reported by al-Bīrūnī has not been included in the Figure as it is only an isolated example.

It is immediately apparent from Figure 4.3 that the predictions made by al-Battānī around the turn of the tenth century AD are greatly inferior to those made by the other astronomers. Al-Battānī used the tables in Ptolemy's *Almagest* to make these predictions. These tables were already more than seven hundred years old by this time, and so it is not surprising that they were beginning to give inaccurate predictions. This was caused by the cumulative effect of small errors in Ptolemy's parameters over many years, and, as I have discussed in Section 4.2 above, it was errors in predicting of eclipses that were largely responsible for the attempts by the Islamic astronomers to make improvements to Ptolemy's parameters in their *zījes*.

The tables used by al-Māhānī to make his predictions during the ninth century AD are not known. They are of comparable accuracy to the tables of Ḥabash used by Banū Amājūr in about AD 960, and so I would suggest that either these tables, or ones based upon them,[19] were used. It is interesting that the *al-Mumtaḥan Zīj*, used by Ibn Yūnus at the end of the tenth century AD, appears to be slightly more accurate than the *zīj*es of Ḥabash. This *zīj* was compiled by Yaḥyā ibn Abī Manṣūr at the start of the ninth century AD, some thirty or forty years before the *zīj*es of Ḥabash. This could suggest one of two possibilities: either the *al-Mumtaḥan Zīj* was more accurate than the later *zīj*es of Ḥabash, or Ibn Yūnus applied the tables more reliably than Banū Amājūr.

Overall, the medieval Islamic astronomers of the near east achieved a considerable level of accuracy in timing eclipses. At no earlier period of history, be it in Mesopotamia, Ancient Europe or China, had it been possible for eclipses to be timed to an accuracy of better than 10 minutes. Furthermore, using the *zīj*es that they compiled, the Islamic astronomers were able to predict the time of an eclipse to an accuracy of better than 20 minutes. Again this is a considerable achievement.

[19] Of which there were several. See Kennedy (1956).

Chapter 5

Later Medieval and Renaissance Europe (c. AD 1250 – 1600)

> "Astronomy" and "astrology" differ in the former's taking its name from the phrase "law of the stars," while the latter takes its from the phrase "discourse concerning the stars" — for *nomia* means law, and *logos*, discourse. It is astronomy, then, which treats the law of the stars and the revolution of the heavens and which investigates the regions, orbits, courses, risings, and settings or stars, and why each bears the name assigned it; it is astrology, however, which considers the stars in their bearing upon birth, death, and all other events, and is only partly natural, and for the rest, superstitious ... it is the "mathematicians" who traffic in the superstitious part.
>
> — Hugh of St. Victor, c. AD 1130; translated by J. Taylor (1974)

5.1 Introduction

After the fall of the Greek and Roman Empires, scientific learning in Europe went into a period of decline. By the latter half of the first millennium, the works of Ptolemy and other Greek astronomers had been lost in Western Europe, fortunately to survive in Arabic translations in the Near East. But that is not to say that astronomy had no place in Medieval Europe. Instead, a new form of "practical" astronomy developed whose goals were to assist in solving some of the problems, such as determining the date of Easter and the times of prayers in monasteries, of religious and civil life (McCluskey 1998). By the twelfth century AD, however, interest in science had been rekindled and there began a search to recover ancient scientific texts. This led to the many scientific achievements made in the fifteenth and sixteenth centuries AD during the Renaissance.

The general outline given above is applies throughout the whole of Europe with one notable exception: Spain. At the end of the seventh century AD, Ṭāriq b. Ziyād and Mūsā b. Nuṣayr conquered Spain. The northern half of the country was soon recaptured by the Christians, but it was not until AD 1492 that the Muslim strongholds in the south finally fell. In the early part of this period there was a significant amount of contact between the Islamic astronomers based in the Near East, and those in southern Spain. However, due to the difficulty of long-range communication, and also some political problems, in later periods the most recent astronomical writings were not always available to the Spanish scholars (King 1996). This resulted in the astronomical developments made in Spain gradually becoming less dependant on those made in the rest of the Islamic World (Samsó 1991). Nevertheless, it was through southern Spain that Islamic astronomy was transmitted first to northern Spain, and then to the rest of Europe, in the fourteenth and fifteenth centuries AD.

There are two main sources of astronomical records in European history: accounts of noticeable celestial events recorded in various historical chronicles, and, from the fourteenth century AD onwards, various treatises and other assorted manuscripts written by astronomers, some of which contain detailed descriptions of astronomical observations. The reports of observations recorded in the chronicles are generally very descriptive, but, on the whole, lack technical precision.[1] They will therefore not be considered further in this study. Of much greater interest are the works written by astronomers. These range from published treatises such as Copernicus' *De Revolutionibus*, to astronomical tables and their explanatory canons, to miscellaneous collections of manuscripts on astronomical subjects.

Unlike most of the eclipse records made in other parts of the world, which were made by anonymous astronomers or groups of astronomers, all of reports from Later Medieval and Renaissance Europe were made by identifiable astronomers.[2] Thus, it is possible to directly compare the observations and predictions of eclipses by these different observers to determine their relative accuracy. This will be the main subject of the present chapter. Before this, however, it is necessary to make some introductory remarks on the use of astronomical tables to predict eclipses, and on the instruments and techniques used by the astronomers in their observations. Part of the introductory discussion and most of the material regarding the observations made by Regiomontanus and Bernard Walther is drawn from Steele & Stephenson (1998b).

5.2 European Astronomical Tables

One of the most important legacies of Islamic astronomy in Europe was the tradition of compiling astronomical tables. The earliest tables found in Europe are from Spain. Examples of these include the *zījes* of al-Khwārizmī and al-Battānī, which were imported from the Near East. It was not until the second half of the eleventh century, however, that a set of astronomical tables was actually compiled in Europe. These were the *Toledan Tables*, described by Samsó (1991: 14) as "a hasty adaptation of all the available astronomical material (al-Khwārizmī, al-Battānī and the *Almagest*) to the coordinates of Toledo".[3] The tables themselves were not very successful; nevertheless, they were used in Spain, and also parts of Christian Europe, for the next two centuries.

Towards the end of the thirteenth century, King Alfonso X of Castille patronized an important body of scientific work.[4] This included a collection of translations of Islamic astronomical works, a collection of treatises on the use of various astronomical instruments and a star catalogue, known as *Los libros del saber de astronomia*, and, most famously, a set of astronomical tables known as the *Alfonsine Tables* (Procter 1945). All of these works were written in Castilian; however, they are not all extant in their original form. In particular, the *Alfonsine Tables* are only known in Latin. In the prologue to the tables it is written that they were compiled by two Jewish astronomers, Isaac ben Sid and Jehuda ben Moses Cohen, under the direction of the king (Procter 1945); however Poulle (1988) has argued that the Latin version of the *Alfonsine Tables* was not a translation of the Castilian original, but a new set of tables compiled in Paris by Jean de Murs in the fourteenth century. The original contents of the Castilian tables appear to have been lost.

Appended to all of the extant copies of the (Latin) *Alfonsine Tables* are a series of treatises, usually known as "canons", describing how to use the tables. These are certainly all original Latin works and are attributed to specific authors such as Jean de Murs and Jean de Saxe.[5] The *Alfonsine Tables* were quickly distributed throughout Europe where they achieved great popularity. One of their principal uses was in predicting eclipses. For example, Thorndike (1951, 1952, 1957) has uncovered a number

[1]A wide spectrum of astronomical events are reported in the chronicles including solar and lunar eclipses, meteors, and comets.

[2]With the exception of some of the eclipse records in the historical chronicles. However, as I have said, these records will not be used in the present study. For details of the eclipse records in the chronicles, see Newton (1972) and Stephenson (1997b).

[3]For a detailed description of the *Toledan Tables*, see Toomer (1968).

[4]Note, however, that Alfonso patronage was not limited to scientific works; he also sponsored books of historical, legal and literary studies. For limited biographical details of Alfonso, see Thomas (1970) and the references therein.

[5]The canon of Jean de Saxe and the *Alfonsine Tables* have been translated into French by Poulle (1984). Extracts have also been translated into English by Thoren & Grant (1974).

of manuscripts containing predictions of eclipses made with these tables for several years in the fourteenth and fifteenth centuries AD. Unfortunately, the meridians used in making these predictions are not known,[6] and so it is not possible to evaluate the quality of these predictions.

The basic astronomy of the *Alfonsine Tables* was Ptolemaic, although minor modifications were made to a number of the parameters based upon more recent observations. Despite their general acceptance throughout Europe, it did not take long before they began to be criticized. Levi ben Gerson, a French Jew working in Orange, does not mention them specifically, but gives a more general criticism of Ptolemy's lunar model. Based upon his own observations,[7] he proposed an alternative lunar model which attempted to correct for the differences he noted between Ptolemy's model and his observations. He compiled his own set of astronomical tables, which have been edited by Goldstein (1974), but it is not clear what impact they had on other astronomers of the time. They certainly did not rival the *Alfonsine Tables* in popularity.

The reliability of the *Alfonsine Tables* came to be increasingly questioned during the latter half of the fifteenth century. This criticism largely came from the city of Vienna, where Georg Peurbach and his student and associate Regiomontanus worked. Peurbach, a member of the faculty at the University of Vienna and court astrologer to King Ladislaus V, is most famous for his work the *Tabulae eclipsium*, probably completed in AD 1459.[8] These tables were derived entirely from the *Alfonsine Tables* but, due to their arrangement, allowed the circumstances of solar and lunar eclipses to be calculated with greater ease. However, after observing a lunar eclipse on the 3rd September 1457 AD, Peurbach noted that the time did not agree with that given by the Alfonsine calculations by nearly 10 minutes, and began to formulate improvements. Unfortunately he died in AD 1461 before the completion of this work. However, some fifty years later, Johannes Angelus, also from Vienna, published annual ephemerides that he claimed were based upon Peurbach's corrections to the *Alfonsine Tables*, and completed by himself (Dobrzycki & Kremer 1996). Undoubtably, Peurbach discussed his misgivings about the *Alfonsine Tables* with Regiomontanus, who by AD 1464 was able to write to the Italian astronomer Giovanni Bianchini declaring that the astronomy of the *Alfonsine Tables* were incorrect (Swerdlow 1990). Indeed he went so far as to accuse the astronomers who blindly accepted them of great indolence:

> "... I cannot but wonder at the indolence of the common astronomers of our age who, just as credulous women, receive as something divine and immutable whatever they come upon in books either of tables or their canons, for they believe in writers and make no effort to find the truth."
>
> [MS Nuremberg Cent V app. 56c; trans. Swerdlow (1990: 170–171)]

Regiomontanus intended to reform the astronomy of the *Alfonsine Tables* by means of the application of Ptolemy's methods to new observations. However, he was never to complete this task (he died in AD 1476), and it was not until Copernicus published *De Revolutionibus* in AD 1542 that his intentions were fulfilled. Although the astronomy of *De Revolutionibus* placed the Sun at the centre of the planetary system, in its methods it was still Ptolemaic. In AD 1551 Erasmus Reinhold, a mathematics professor at the University of Wittenberg compiled the *Prutenic Tables* based upon parameters derived from Copernicus' observations (Swerdlow 1996). These tables came to replace the *Alfonsine Tables* throughout Europe until the middle of the seventeenth century AD when Kepler's *Rudolphine Tables* finally came to be widely accepted (Swerdlow 1996). The *Rudolphine Tables* were compiled by Kepler from his theories of planetary motion derived from Tycho Brahe's observations. Tycho had himself noted significant errors in both the *Alfonsine Tables* and the *Prutenic Tables*. However, although he proposed his own Earth-centred cosmology with the Sun carrying the planets revolving around the Earth, he did not publish any tables to replace them.

[6]Thorndike (1957) suggests Oxford for some of them, but I do not believe that there is sufficient justification to make this claim.

[7]Levi ben Gerson was almost unique in the Medieval World in mainly using his own observations, rather than those of the ancients, to construct his astronomical models (Goldstein 1972; Goldstein 1974).

[8]For a biography of Peurbach, see Hellman & Swerdlow (1978).

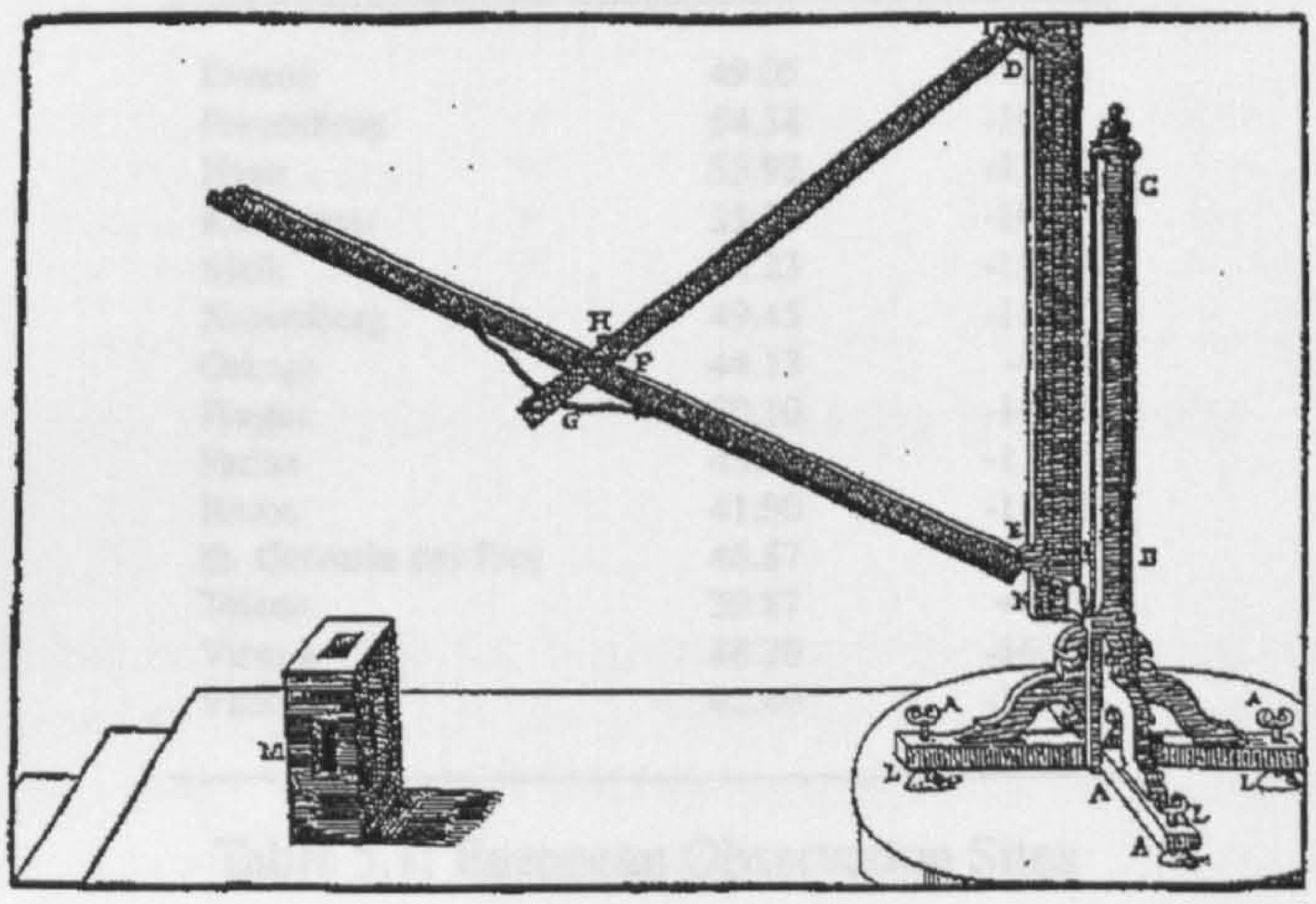


Figure 5.1: Tycho Brahe's drawing of the Ptolemaic ruler from *Astronomiae Instauratae Mechanica.*

5.3 Observational Techniques and Instruments

In addition to the tradition of compiling astronomical tables, Islamic astronomy also profoundly influenced the way that astronomers of the Later Medieval period made astronomical observations. In particular, Islamic astronomers had concluded that clepsydras were not reliable enough to make accurate time measurements. It was deemed better to determine the time indirectly using measurements of the altitude of the Sun, Moon or fixed stars. This practice was inherited by Later Medieval European astronomers.

The most important instrument used to measure altitudes was the astrolabe. This device consists of a circular plate, one side of which contains a graduated scale and an alidade.[9] The other side of the plate contained a moveable rete over an inscribed base which could be used to convert the altitude measurements to a local time. Thus the astrolabe functioned both as an observational instrument, and as an analogue computing device for converting altitudes to local times.[10] The limiting factor in the reliability of an astrolabe is often the accuracy with which the scale is graduated. Chapman (1983) has made a study of a number of European astrolabes of this period and found that is most cases these scales are typically accurate to about 5 minutes of arc. This is equivalent to better than 1 minute of time.

Another instrument widely used among European astronomers for measuring altitudes was the quadrant. As its name suggests, this instrument consists of a graduated quarter-circle plate fixed with one edge horizontal but allowed to rotate to any direction of azimuth. An alidade, fixed at what would be the centre of the circle, could then be used to measure the altitude of a star. A third instrument that could be used to determine altitudes was the Ptolemaic ruler. This simple instrument consisted of three rulers, two of which were attached with hinges to the ends of the third, which was itself held vertical. The free end of one ruler was then allowed to slide along the length of the other, forming a triangular shape with an inclined base which extended beyond the apex of the triangle. The construction of the Ptolemaic ruler can be seen more clearly from Figure 5.1 which is a reproduction of Tycho Brahe's drawing of the instrument from the *Astronomiae Instauratae Mechanica* (Brahe 1598).

Around the end of the fifteenth century AD, mechanical clocks started to be used by European

[9] An alidade is basically a straight edge used for sighting the reference object and then used as a marker on a graduated scale.

[10] For a full discussion of the construction and use of an astrolabe, see North (1974).

City	Latitude (°)	Longitude (°)
Evreux	49.05	-10.18
Frauenberg	54.34	-19.67
Hven	55.92	-12.75
Knudstrup	55.30	-10.87
Melk	48.23	-15.35
Nuremberg	49.45	-11.08
Orange	44.13	-4.80
Prague	50.10	-14.42
Padua	45.40	-11.88
Rome	41.90	-12.48
St. Germain des Pres	48.87	-2.33
Toledo	39.87	+4.03
Vienna	48.20	-16.37
Viterbo	42.40	-12.10

Table 5.1: European Observation Sites

astronomers. Regiomontanus appears to have been a pioneer among astronomers in using a clock (Zinner 1990: 138). However, although some other astronomers, most notably Bernard Walther, used clocks in their observations, many others decided that the available devices were not sufficiently accurate and so continued to determine the time from stellar altitudes following the Islamic tradition.

5.4 Timed Eclipse Records in Later European History

There would appear to have been very little interest in observing eclipses by European astronomers in the Later Medieval and Renaissance periods. Indeed, before the beginning of the seventeenth century AD, only seven astronomers are known to have made detailed timed observations of eclipses: Isaac ben Sid, Levi ben Gerson, Jean de Murs, Regiomontanus,[11] Bernard Walther, Nicholas Copernicus, and Tycho Brahe. This trend was radically reversed during the seventeenth century AD, in particular after the invention of the telescope when many astronomers began to make systematic observations of eclipses.[12] It is quite possible, however, that other earlier astronomers did record observations of eclipses in works that have now been lost.

The sources in which the observations of the above mentioned astronomers are found vary widely. Some, for example those by Isaac ben Sid and Jean de Murs, are found in manuscripts that have only recently been found. Others, for example those by Regiomontanus, Walther and Copernicus, are contained in works that were published in the sixteenth century AD. In particular, the observations by Regiomontanus and Walther are found in a work entitled *Scripta Clarissimi Mathematici M. Ioannis Regiomontani*. This is a collection of short mathematical and astronomical treatises written by Regiomontanus and Peurbach and collected together by Schoener (1544). He also reports many, but not all, of Regiomontanus' and Walther's astronomical observations. However, this compilation, which was made forty years after the last observation it reports, contains a number of scribal errors, as will be noted in Sections 5.4.4 and 5.4.5 below.

Before discussing the observations made by the Later Medieval and Renaissance European astronomers in detail, it is necessary to make two comments. First, the observations were made from various cities throughout Europe. These are listed, together with their geographical latitude and longitude in Table 5.1. The second comment concerns the calendars which the European observers used. With the exception of one observation by Tycho Brahe (in AD 1600) which uses the Gregorian calendar, all of the reports use the Julian calendar. However, there was no consensus through Europe on the

[11] Some of Regiomontanus' eclipse observations were made jointly with Georg Peurbach.

[12] See, for example, the many eclipse observations collected by Pingré (1901).

			Local Time (h)		
Date	Type	Contact	Predicted	Observed	Computed
1263 Aug 5	Solar	M	5.05	14.00	14.27
1265 Dec 24	Lunar	M	20.66	3.66	3.42
1266 Jun 19	Lunar	M	-	3.13	3.40
1266 Dec 13	Lunar	M	-	18.62	18.74

Table 5.2: Eclipse observations made by Isaac ben Sid.

date on which the year began. For example, Regiomontanus started the year on the 1st January, but Levi ben Gerson chose the 1st March as the date of New Year. In some parts of Europe the 25th March was used. Throughout this study, however, I shall always use the 1st January as the date of New Year. All Julian dates after the introduction of the Gregorian calendar in AD 1582 will be converted to this latter system.

5.4.1 Isaac ben Sid

Isaac ben Sid was one of a number of Jewish scholars at the court of King Alfonso X of Castille during the thirteenth century. Together with Jehuda ben Moses Cohen he was responsible for compiling the *Alfonsine Tables*. As part of the preparation for compiling the tables, the two astronomers made a number of observations of the path of the Sun throughout the year, planetary conjunctions, and lunar and solar eclipses (Procter 1945). Little is known of the life of ben Sid either before of after the compilation of the *Alfonsine Tables*; ben Moses Cohen is known to have been involved in translating some of the Arabic texts for Alfonso's *Los Libro de las Estrellas*, but ben Sid does not appear to have been involved in this project.

No contemporary record of Isaac ben Sid's astronomical observations is known; however, some forty years later Isaac Israeli of Toledo reported four of ben Sid's eclipse observations in his astronomical work *Jesod Olam.*[13] This work is unavailable to me at present; fortunately, however, the eclipse observations have been described by Goldstein (1979). The three lunar eclipses were observed on the 24th December 1265 AD, the 19th June 1266 AD, and the 13th December 1266 AD. The solar eclipse was observed on the 5th August 1263 AD. In each case the observed time of mid-eclipse in Toledo is reported; in addition, for the solar eclipse and the first lunar eclipse, the predicted time of mid-eclipse is given. It is reasonable to suppose that these predicted times were calculated from the *Toledan Tables*. It is not known how Isaac ben Sid determined the observed times of the eclipses, but I would suggest that, following the practice of the Islamic astronomers,[14] he measured the altitude of either the eclipsed luminary or of a clock-star and converted this into a local time.

Isaac ben Sid's eclipse observations are summarized in Table 5.2. The mean accuracy of the observed times is about 0.23 hours. It is clear, however, that the times predicted using the *Toledan Tables* are extremely inaccurate — both of the two predicted times are early by more than 7 hours. As there are only two predicted times it is meaningless to try to determine the typical accuracy of the *Toledan Tables* from these records, but if nothing else I may note errors of more than 7 hours are very serious and are in not way comparable with the eclipse predictions made with the *zījes* compiled by the Islamic astronomers.

[13] c.f. Dreyer (1920) who incorrectly remarks that Isaac Israeli only refers to three eclipse observations.

[14] See Section 4.3 above.

5.4.2 Levi ben Gerson

Levi ben Gerson lived and worked in Orange,[15] France during the first half of the fourteenth century AD.[16] A Jewish scholar, he was fortunate to live in this part of France for it escaped the expulsion of the Jews from the country by King Philip the Fair in AD 1306. He worked in a number of different fields, writing on mathematics, astronomy, philosophy, and religion. There is no evidence that ben Gerson knew either Latin or Arabic; he seems to have worked from Hebrew translations of ancient books. All of his works were written in Hebrew, although some, including his philosophical treatise the *Milḥamot Adonai*, were later translated into Latin.

The *Milḥamot Adonai* ("The Wars of the Lord") is commonly regarded as Levi ben Gerson's greatest work. It comprises six books, of which the fifth is devoted to astronomy. The first draft of the astronomical treatise was completed in AD 1328 but did not reach its final form until AD 1340. Some of the observations that ben Gerson made as part of this work date from AD 1321, and so it is clear that the final version of the astronomical treatise represented the culmination of many years of work. The main part of the treatise is comprised of a set of astronomical tables. These have been edited by Goldstein (1974). Another part of the treatise contains a discussion of an instrument known as the Jacob's Staff. This instrument, which ben Gerson claimed to have invented, is made up of two moveable pieces of wood in the form of a cross and can be used to measure angular differences between stars.[17]

In constructing his astronomical tables, Levi ben Gerson made extensive use of his own observations (Goldstein 1972). Amongst the observations are 10 accounts of eclipses. These are recorded in chapters 80 and 100 of the *Milḥamot Adonai*, which have been translated by Goldstein (1979). In many cases ben Gerson reports not only the observed details of the eclipse, but also its circumstances calculated using his tables. As an example, I quote below ben Gerson's account of the lunar eclipse on the 3rd October 1335 AD.

> "The fifth eclipse took place in the year 1335. The end of this eclipse was 1;24 hours before sunrise of 3 October as determined with our accurate instruments. This was the first night to the festival of *Succot*, and there was present with us a noble Christian who wrote down all that we observed. The Moon remained in darkness (i.e., totality) 0;44 hours as most accurately determined."
>
> [*Milḥamot Adonai*, 80, 22–25; trans. Goldstein (1979: 110)]

In chapter 100, ben Gerson also notes that the time of the middle of the eclipse was 15;19 hours after apparent noon, and so the time of 2nd contact was 14;57 hours after apparent noon, and that of 3rd contact was 15;41 hours after apparent noon. He further notes that the time of the end of the eclipse calculated from his tables is 16;51 hours after apparent noon, 6 minutes earlier than observed. It is not known how ben Gerson made his time measurements, but I may once more speculate that they were obtained from altitude measurements.

Levi ben Gerson's eclipse observations and predictions are summarized in Table 5.3. The mean accuracy of the observed times is about 0.16 hours. However, it appears that ben Gerson's observed times are subject to a systematic error; their mean error is about +0.14 hours. The cause of this error is unknown. Perhaps he attempted to correct for the delay in detecting the true moment of an eclipse contact and overestimated the time interval between a true and an apparent contact.[18] The mean true accuracy of ben Gerson's eclipse predictions is about 0.25 hours, but once more these are subject to a systematic error, this time of about +0.23 hours. The mean observed accuracy of the predictions,

[15] Levi calls this town *'ir ha-ezov* in Hebrew, which is translated into Latin as Aurayca. On the identification of Aurayca with Orange, see Goldstein (1974: 19–20).

[16] For a detailed biography of ben Gerson, see Samsó (1973).

[17] For a description of the Jacob's Staff, see Samsó (1973).

[18] It is not conceivable that the error is caused by use of an incorrect value for ΔT, the Earth's rotational clock error, since it is only of the order of 400 seconds at this period.

			Local Time (h)		
Date	Type	Contact	Predicted	Observed	Computed
1321 Jun 26	Solar	1	4.55	4.41	4.56
		M	-	5.28	5.50
1321 Jul 9	Lunar	1	3.00	-	3.21
1330 Jul 16	Solar	M	16.30	-	16.67
1331 Dec 14	Lunar	4	5.83	-	6.25
1333 May 14	Solar	M	-	15.50	15.49
		4	-	16.63	16.76
1333 Oct 23	Lunar	M	20.12	-	20.54
1334 Apr 19	Lunar	4	23.97	0.00	0.34
1335 Oct 3	Lunar	2	-	2.88	2.98
		3	-	3.65	3.67
		4	5.03	4.73	4.94
1337 Mar 4	Solar	1	7.33	7.29	7.33
		4	9.33	9.30	9.65
1339 Jan 26	Lunar	1	-	4.50	4.42

Table 5.3: Eclipse observations made by Levi ben Gerson.

however, is about 0.11 hours, with no significant systematic error. The fact that ben Gerson did not observe any systematic error in his predictions is unsurprising since his tables were based upon his own observations. Therefore, any systematic error in his observations would be carried through to his predictions.

5.4.3 Jean de Murs

Working mainly in Paris and the surrounding areas, Jean de Murs was active in the field of science from about AD 1317 to about AD 1345.[19] Like many European scholars of this period, however, de Murs did not restrict himself to one discipline, but had a range of interests spanning astronomy, mathematics and music. During his life he wrote a number of books on all of these subjects. In astronomy, he is most widely known as the author of a set of canons for the *Alfonsine Tables* first begun in AD 1321 but not completed until AD 1339. Furthermore, as noted above, Poulle (1988) has suggested that Jean de Murs may have been the author of the Latin version of the *Alfonsine Tables* that were used throughout Europe from the fourteenth century AD.

By AD 1321, Jean de Murs had become a master of arts at the Sorbonne in Paris where he was to continue to work for many years. However, a manuscript uncovered by Professor Guy Beaujouan at the Escorial Library,[20] has revealed that he continued to travel throughout France during this period (Gushee 1969). In AD 1333 he traveled to Evreux, near St. Germain, where it would appear he held at least two official positions. Whilst there he observed an eclipse of the Sun on the 14th May. His observation is recorded in the Escorial Manuscript. This has been published by Beaujouan (1974). I give below a translation of de Murs' account of the eclipse:

> "[In the current year of our Lord 1333, on the 14th day of May] ... At Evreux, in the region of St. Germain, 3 brothers and I, in the presence of the Queen of Navarre, observed the beginning of this eclipse. And the altitude of the Sun at the initial point of the eclipse was near to 50°, and the altitude at the end of the eclipse was 33°. The digits (*puncta* — i.e., magnitude) of the eclipse, according to our estimate, was 10 digits; a smaller (i.e., more precise) discernment was not possible. And so the beginning of the eclipse was after our midday by 2 hours and 20 minutes."
>
> [Escorial, MS O.II.10, fol. 92]

[19] For detailed biographical accounts of Jean de Murs, see Poulle (1973) and Gushee (1969).
[20] Escorial, MS O.II.10.

Jean de Murs then notes that the eclipse occurred about 17 minutes earlier than was predicted by the *Alfonsine Tables*.

By AD 1336, de Murs had returned to the Sorbonne in Paris. The following year he was to observe another eclipse from nearby St. Germain des Pres. This solar eclipse, also reported in the Escorial Manuscript, took place on the 3rd of March:

> "In the year of our Lord 1337, on the 3rd day of March, after the Sun rose. That day, in St. Germain des Pres, we saw the beginning of the eclipse of the Sun. The Sun was at an altitude of 10°, and already a (small) part was eclipsed, from which we concluded that the peripheries of the luminaries could have touched (when they were) at an altitude of 9°. Similarly, we saw that the Moon left contact with the Sun, as much as (it) was possible (to see), (when) the Sun was at an altitude of 27° and about 30'. However, at Paris, the Alfonsine Tables placed the beginning of the eclipse of the Sun (when) the Sun had an altitude of 14° ... It finished, I think, at an altitude of 29° as it was seen at an altitude of $27\frac{1}{2}$°. Therefore, I consider it necessary to quickly correct and make known the errors in placing eclipses by the Alfonsine Tables. And it follows similarly from the preceeding eclipse in the year 1333. That one anticipated the tables by about a third of an hour ... The tables place the amount in darkness as 7 digits (*puncta*) of the diameter. However, it was only 5 digits. In this experiment there were 10 of us present and a number had good astrolabes."
>
> [Escorial, MS O.II.10, fol. 93]

It is interesting to note de Murs' attitude towards the inaccuracy of the *Alfonsine Tables*. He found errors of about one-quarter of an hour between the tables and observation to be unacceptable, but when they are compared to the errors observed by earlier Islamic astronomers,[21] this does not seem to be too bad. Nevertheless, de Murs remarks that "it is necessary to quickly correct and make known the errors" in the tables. Perhaps this was to form the stimulus for his revision of his canon to the tables in AD 1339. More speculatively, it is possible that the extension of his dissatisfaction with the accuracy of the *Alfonsine Tables* may have led to him compiling his own tables to replace them. These could have become the Latin *Alfonsine Tables* which Poulle (1988) has already suggested may have been authored by de Murs.

After AD 1337, no further eclipse records by de Murs are known. However, this was not the end of his interest in astronomy. In AD 1344, de Murs, together with Firmin de Belleval, was called to Avignon by Pope Clement VI to discuss calendar reform (Poulle 1973). His suggestions, which were published as a memoir in AD 1345, were not, however, adopted. Later, at some point before AD 1352, de Murs wrote to Clement VI to inform the pope of the favourable conditions for a crusade in AD 1365 signified by a conjunction in that year. This is the latest evidence we have for de Murs' work, and it would appear that he died shortly after this date.

Jean de Murs eclipse observations are summarized in Table 5.4. With the exception of the time of first contact of the eclipse in AD 1333, the timings are very accurate, having a mean accuracy of about 0.08 hours. Including this timing, the mean accuracy is about 0.21 hours. Furthermore, there is no evidence for any systematic errors in the timing. The mean true accuracy of the times calculated from the *Alfonsine Tables* is about 0.09 hours, which is very impressive at this comparatively early period. The mean observed accuracy is only 0.28 hours, but this is still fairly good and does not seem to justify de Murs' harsh criticism of the tables. It is interesting to note that both of these eclipses were also observed by Levi ben Gerson. With the exception of the inaccurate first contact timing of the eclipse in AD 1333, the two astronomers reached a comparable level of accuracy in both observing and predicting the times of these eclipses.

5.4.4 Regiomontanus

Johannes Muller of Konigsberg, who later adopted the name Regiomontanus, enrolled in the University of Vienna in AD 1450 at the age of fourteen, and within two years had been awarded his bachelor's

[21] See Section 4.4 above.

Date	Type	Contact	Object	Altitude (°) Observed	Computed	Local Time (h) Predicted	Observed	Computed
1333 May 14	Solar	1	Sun	50.00	54.44	14.02	14.33	13.76
		4	Sun	33.00	31.20	15.90	16.18	16.21
1337 Mar 3	Solar	1	Sun	9.00	9.55	6.93	7.20	7.26
		4	Sun	29.00	27.69	9.34	9.61	9.43

Table 5.4: Eclipse observations made by Jean de Murs.

degree.[22] He was quickly befriended by Georg Peurbach, often referred to by Regiomontanus as "my teacher," and together they began making a study of astronomy. Their earliest observation for which a record is preserved is of the lunar eclipse on the 3rd September 1457 AD. This was made at Melk castle, a short distance to the west of Vienna. Because of the low precision of the mechanical clocks of the period, Regiomontanus used an astrolabe to measure the altitude of the star 27 Tau and thus to determine the time when the eclipse started and finished. He then proceeded to deduce the time of the true opposition and compared the observed time with that calculated by the *Alfonsine tables*, noting a significant error.

One month later, on the 11th November, Regiomontanus was appointed to the faculty of the University of Vienna. He remained there for the next four years, during which time he observed another three lunar eclipses. Again he obtained the times of the eclipses by measuring the altitudes of either bright stars or the Moon itself, and then made a comparison with the times given by tables. These tables were probably Peurbach's *Tabulae eclipsium*, which Regiomontanus had copied during this period.

In AD 1460, Cardinal Bessarion, the papal legate to the Holy Roman Empire, visited Vienna, an event that was to drastically change the course of Regiomontanus' life. Bessarion asked Peurbach to write a commentary or *Epitome* of Ptolemy's *Almagest*, and to accompany him to Rome. Peurbach accepted on the condition that Regiomontanus was to travel with them. However, before they departed, Peurbach fell ill and died, leaving Regiomontanus to complete the writing of the commentary and to travel to Rome alone with Bessarion. They left in the autumn of AD 1461, and arrived in Rome on the 20th November (Zinner 1990: 51).

Regiomontanus was to spend the next five years in Italy. During this period, he was to complete the writing of the *Epitome* of the *Almagest*, enter into his correspondence with Bianchini and continue making astronomical observations. He observed two lunar and one solar eclipse over the next year, either in Rome itself, or in nearby Viterbo.

In AD 1464, Regiomontanus moved to Padua where he gave a number of lectures. Whilst in Padua, he observed the lunar eclipse on the 21st April, once again measuring the altitude of two bright stars at the moment that the eclipse began. He used an instrument called the "great quadrant" to make these measurements. This quadrant evidently allowed Regiomontanus to make much more precise determinations of altitude than his usual instruments, for he quotes the altitudes to the nearest five minutes of arc, instead of to his usual degree or half-degree.

After his time in Padua, Regiomontanus returned to Rome, before moving to Hungary in AD 1467 to join the faculty of the University of Pressburg. Here he remained until AD 1471 when he was invited to Nurenberg and given a Royal Commission to make celestial observations. In Nurenberg, Regiomontanus met Bernard Walther, who was to become his pupil and associate, and may possibly have acted as his financial backer. Regiomontanus set up a print shop to publish scientific works (mainly those written by himself and Peurbach), and began making systematic observations. For this purpose, Regiomontanus built a Jacob's staff and a Ptolemaic Ruler (Zinner 1990: 141); however, it is not clear whether he used either of these instruments during his eclipse observations. Furthermore,

[22] For a detailed biography of Regiomontanus, see Zinner (1990) and Rosen (1975).

there is no evidence that Regiomontanus had a purpose built observatory, despite claims made during the nineteenth century that Walther had built him one.

Shortly after arriving in Nurenberg, Regiomontanus observed the lunar eclipse on the 2nd June 1471 AD. This was to be his final recorded eclipse observation, although his programme of stellar and planetary observations was only just beginning. At the end of June 1475 AD, Regiomontanus was summoned to Rome by Pope Sixtus IV to participate in the discussions on the reformation of the calendar (Zinner 1990: 151). But by AD 1476, he had died, perhaps murdered, at the age of 40.[23]

In all, Regiomontanus observed nine eclipses in Vienna, Rome, Padua, and Nurenberg. These are reported in Schoener's *Scripta Clarissimi Mathematici M. Ioannis Regiomantani*,[24] which was compiled from Regiomontanus' notebooks some sixty-nine years after Regiomontanus' death. Below I give translations of the relevant parts of the report of each observation:[25]

- 3 September 1457 AD

> "Master Georg Peurbach and Johannes Regiomontanus observed in Melk, Austria, near Vienna, in the year of our Lord 1457 a total eclipse of the Moon at the true opposition in September, namely after sunset on the 3rd day of the month. Moreover, at the beginning of totality the penultimate star of the Pleiades (27 Tau) had an easterly altitude of 22 degrees, and according to calculation the Sun was 48 minutes in the 20th degree of Virgo. However, at the end of totality the altitude of this same star was 36 degrees. This observation was at Melk castle in Austria, which is distant from Vienna 11 German miles towards the west. From these two altitudes of the said star, the actual time of mid-eclipse can be calculated ..."
> Note: There follows a long calculation in which the time of true opposition is deduced as 11 hours 6 minutes, which compares with the time calculated from the *Alfonsine Tables* of 11 hours 14 minutes.

- 3 July 1460 AD

> "There was a partial eclipse of the Moon during the night which followed the 3rd day of July; its beginning was exactly 7 hours 16 minutes after midday. Moreover, the middle (was) at 8 hours 13 minutes and the end occurred at 9 hours 10 minutes; (it was) 2;56 ecliptic digits. This (was) according to the tables for the meridian of Vienna. However, I myself observed the middle of this eclipse in the sky, and it seemed to be eclipsed rather more than four digits. Moreover at the end I measured the altitude of the Moon as 15 degrees 18 minutes. Also present was Georg, my teacher."

- 27 December 1460 AD

> "In the same year there was a total eclipse of the Moon at the true opposition of the luminary, which was the 27th day of December, in which by observation at the start of the eclipse the star which is called *Alramech* (α Boo) had an altitude in the east of 7 degrees. At the beginning of totality the altitude was 17 degrees and at the end of totality the altitude was 28 degrees. At the beginning of the eclipse the Moon was seen on a great circle passing through the head of the preceding Twin (α Gem) and the bright (star) of Canis Minor (α CMi). However, at the end it was above a circle passing through the head of the following Twin (β Gem) and Canis Minor. The observers were Georg Peurbach and Johannes Regiomontanus in the town of Vienna."

[23]Shortly after Regiomontanus' death, rumours spread that he had been the victim of a terrible crime. The sons of Trebizon, whose translation of the *Almagest* Regiomontanus had criticized, were said to have murdered him. However Zinner (1990: 152) notes that there is little evidence in support of this story, and suggests instead that Regiomontanus was probably the victim of a plague that was epidemic in Rome in that year.

[24]Schoener (1544). Regiomantanus' observations are given in folios 36–43, entitled *Ioannis de Monteregio, Georgii Peurbachii, Bernardi Waltheri, ac aliorum, Eclipsium, Comentarum, Planetarum ac Fixarum observationes*.

[25]These translations are those published in Steele & Stephenson (1998b).

- 22 June 1461 AD

"There was a total eclipse of the Moon at the opposition of the luminary, which was the 22nd day of June. Moreover, at the beginning of totality the altitude of the Flying Vulture (α Aql) was 26 degrees; the Moon was then noted at an altitude of 6 degrees 30 minutes. At the end of the whole eclipse, the altitude of the Vulture (α Aql) was 47 degrees 30 minutes. Master Johannes Regiomontanus noted the altitude of the Moon as 17 degrees 30 minutes in the town of Vienna. It was therefore probable that the opposition of the luminary occurred one hour and 21 minutes after midnight. By calculation using tables, this occurred one hour and 20 minutes after midnight, a difference of one minute."

Note: It seems probable that the time of opposition Regiomontanus determined both from his observations and from the Alphonsine Tables should be before midnight rather than after midnight. From his altitude measurements, he determined that the eclipse became total just before 9 pm, and that the eclipse ended after 11:30 pm. A time of opposition before 11 pm therefore seems more likely.

- 17 December 1461 AD

"At the start of the following night on the 17th day of December, the Moon rose eclipsed by 10 digits of its diameter. Indeed I merely noted 8 (digits). Moreover, from the Alphonsine computations the end of the eclipse occurred at 1 hour and 56 minutes after sunset. At this same end of the eclipse the altitude of the star *Alhaioth* (α Aur) in the east was 38 degrees 30 minutes, whereas (the altitude of) the star *Aldebaran* (α Tau) was 29 degrees in the east. The location of the Sun according to computation was 5;24 (degrees) in Capricorn. This was in the city of Rome, whose latitude is 42 degrees 2 minutes, although some place it as 41 degrees 50 minutes..."

Note: The text contains a printing error, giving the altitude of *Alhaioth* as 38 minutes 30 seconds instead of 38 degrees 30 minutes.

- 11 June 1462 AD

"On the night which followed the 11th of June, it happened that there was a partial eclipse of the Moon at 15 hours 15 minutes after midday. Moreover, it was eclipsed 6;34 digits according to the tables. I observed the eclipse in Viterbo near Rome, which is believed to be to the east [sic] of Vienna by 4 degrees and a little more according to geography. I could not, however, note the start nor the end on account of obscuring clouds. However, in the middle, the Flying Vulture (α Aql) had an altitude of 51 degrees in the west. I judged that it was eclipsed about 7 digits."

- 21 November 1462 AD

"On the 21st day of November, I observed an eclipse of the Sun about midday. I did not observe the start of the eclipse, but when I caught sight of it, it seemed that two digits of the Sun were eclipsed from the south side. The Sun then had an altitude of $26\frac{1}{2}$ degrees and was due south. Furthermore, at the end of the eclipse, which I carefully noted, the Sun had an altitude of 24;36. The degrees of azimuth of the Sun towards the west of the meridian were 16 degrees 15 minutes. But, as far as I was able to conjecture, it seemed that a third of the time of the whole eclipse had passed from the beginning of the eclipse up to the instant of its first observation. For, a little before (my) first observation, which was precisely at midday, I observed the Sun not yet eclipsed. All from Viterbo near Rome."

- 21 April 1464 AD

"There was a total eclipse of the Moon, namely at its opposition, which was on the 21st of April at fully 12 hours and 59 minutes after midday, in equal hours at the meridian of the city of Padua, whose latitude is said to be 45 degrees 24 minutes. The true place of the Sun was 10 degrees 52 minutes in Taurus from the Alfonsine calculations. Moreover, the Moon was in opposition. The true argument of latitude of the Moon was 5 degrees 25 minutes 23 seconds; the northerly latitude of the moon at the middle of the eclipse was 0 degrees 24 minutes and 5 seconds.

Start of eclipse	11 h 15 m
Start of totality	12 h 33 m
Middle of eclipse	12 h 59 m
End of totality	13 h 25 m
End of eclipse	14 h 43 m
Semi-duration of day	7 h 5 m
Total duration of the eclipse	3 h 28 m

All according to the Alfonsine parameters.
At the beginning of this eclipse I found that the altitude of (the star) at the Heart of the Scorpion (α Sco) was 12 degrees 45 minutes in the east. At the same time also the altitude of α Hyd was 9 degrees 40 minutes by the great quadrant, all (measured) as carefully as possible."

- 2 June 1471 AD

> "On the night of the 2nd of June there was an eclipse of the Moon, at the start of which the Heart of the Scorpion (α Sco) had an altitude in the west of 14 degrees 15 minutes. Further, the Dolphin or Moscida of Pegasus (β Peg) had an altitude in the east of 22 degrees 30 minutes. Four digits appeared to be obscured. Afterwards the Moon appeared to fill up again. The true end did not appear on account of intervening clouds at Nurenberg."

Regiomontanus' eclipse observations are summarized in Table 5.5. Clearly he achieved considerable success in observing his eclipses. The mean accuracy of his altitude measurements is about 0.80°, which corresponds to a mean accuracy in time of about 0.12 hours, or just over 7 minutes. As Regiomontanus generally quotes his altitude measurements to the nearest half degree, it would appear that he was observing at a level of accuracy close to the precision of the instruments that he used. Furthermore, there is no evidence for any significant systematic errors in his measurements; the mean error in his altitudes is about -0.15° which is well within the level of precision of his instruments.

Between AD 1472 and AD 1475, Regiomontanus made a series of observations of the meridian zenith distance of the Sun with his Ptolemaic ruler. As Newton (1982) has shown, these observations typically have an accuracy better than about 2 minutes of arc. This is a significantly better level of accuracy than Regiomontanus achieved during his eclipse observations. However, the instrument was, of course, used for meridian observations. Eclipse contacts would have to be observed rapidly at a wide variety of azimuths and often when the lunar or solar altitude was changing at an appreciable rate. These circumstances would have presented practical difficulties. Furthermore, when observing an eclipse there is the additional problem of defining the exact moment of contact with the unaided eye.

As noted above, one of the main reasons Regiomontanus observed eclipses was to compare his measurements with the calculations given by the *Alfonsine Tables*. From Table 5.5 it is clear that there is a considerable difference between the Alfonsine times on the one hand and both Regiomontanus' observed times and the times given by modern computation on the other. The mean true accuracy of the predicted times is about 0.50 hours, and the mean observed accuracy is about 0.55 hours.

5.4.5 Bernard Walther

Bernard Walther does not generally figure largely in histories of astronomy.[26] He is usually regarded as being Regiomontanus' student and patron and nothing more. This may be because he seems to

[26] Indeed Walther is not even given his own entry in the *Dictionary of Scientific Biography*. For some biographical details, see deB. Beaver (1970). Regarding this article, however, note the cautionary remarks in note 2 of Kremer (1980). For a more recent biographical study, see Eirich (1987).

Date	Type	Contact	Object	Altitude (°) Observed	Altitude (°) Computed	Local Time (h) Predicted	Local Time (h) Observed	Local Time (h) Computed
1457 Sep 3	Lunar	2	27 Tau	22.00	22.97	-	22.48	22.58
		M	-	-	-	23.23	23.10	23.17
		3	27 Tau	36.00	34.68	-	23.89	23.75
1460 Jul 3	Lunar	1	-	-	-	19.27	-	19.97
		M	-	-	-	20.22	-	21.03
		4	Moon	15.30	15.04	21.17	22.14	22.09
1460 Dec 27	Lunar	1	α Boo	7.00	5.01	-	23.71	23.48
		2	α Boo	17.00	14.73	0.78	-	0.54
		3	α Boo	28.00	26.83	1.89	-	1.76
1461 Jun 22	Lunar	2	α Aql	26.00	27.02	-	20.78	20.85
		2	Moon	6.50	6.56	-	20.84	20.85
		M	-	-	-	22.67	22.65	21.72
		4	α Aql	47.50	47.35	-	23.72	23.68
		4	Moon	17.50	17.69	-	23.52	23.68
1461 Dec 17	Lunar	4	α Aur	38.50	39.29	18.50	17.35	17.43
		4	α Tau	29.00	28.16	18.50	17.41	17.43
1462 Jun 12	Lunar	M	α Aql	51.00	51.49	3.25	2.81	2.72
1462 Nov 21	Solar	4	Sun	24.60	24.07	-	12.94	13.12
1464 Apr 21	Lunar	1	α Sco	12.75	13.99	23.25	22.94	23.16
		1	α Hyd	9.66	10.01	23.25	23.20	23.16
		2	-	-	-	0.55	-	0.36
		M	-	-	-	0.98	-	0.79
		3	-	-	-	1.42	-	2.23
		4	-	-	-	2.72	-	2.42
1471 Jun 2	Lunar	1	α Sco	14.25	15.05	-	0.00	23.72
		1	β Peg	22.50	22.43	-	23.73	23.72

Table 5.5: Eclipse observations made by Regiomontanus.

have made no contribution to the development of astronomical theories, but rather to have merely been an observer. However, this is to understate his importance, for he left a legacy of over thirty years' worth of careful observations; observations which would be extensively used by Copernicus, Tycho, and Kepler in testing their planetary theories (Kremer 1981).

Walther came to Nurenberg in AD 1467 and, with his knowledge of Greek, he quickly became known to the group of humanists in the city. When Regiomontanus came to Nurenberg in AD 1471, the two met, a meeting that was to affect Walther's life in the same manner as Regiomontanus' had been when he met Peurbach. First as teacher and student, and then as collaborators, the two men began their programme of systematic observations of the Heavens. After Regiomontanus' death in Rome, Walther continued to observe in Nurenberg until only 16 days before his own death on 19th June 1504 AD (Zinner 1990: 146–147).

Between AD 1478 and AD 1504, Walther observed four solar and two lunar eclipses. In AD 1501 he had two extra south-facing windows built in his house from which it would appear he made his observations. The location of his earlier observation sites in Nurenberg are not known. Like Regiomontanus, Walther often determined the time of an eclipse by measuring the altitude of the luminary, using either a Ptolemaic ruler, or an armillary sphere. However, in AD 1487, he used a mechanical clock to measure the time of the eclipse on the 8th February. In two of his observations, those of AD 1485 and AD 1497, Walther does not state the method he has used to determine the time of the eclipse, but as he is known to have made use of his clock after AD 1484, it seems most likely that he would have used it on these occasions.

Walther's astronomical observations were published in Schoener's *Scripta Clarissimi Mathematici M. Ioannis Regiomantani*,[27] I give below translations of the relevant parts of his eclipse obser-

[27]Schoener (1544). Walther's observations are given in folios 44–60, entitled *Observationes factae per doctissimum virum Bernardum Waltherum Norimbergae.*

vations:[28]

- 29 July 1478 AD

  "July 29. At about the first hour after midday, namely when the Sun's altitude was $54\frac{1}{2}$ degrees, a solar eclipse began. Further, it ended when the altitude of the Sun reached $41\frac{1}{2}$ degrees."

- 16 March 1485 AD

  "On the 16th day of March there was an eclipse of the Sun, beginning 3 hours and 26 minutes after midday; the end was at 5 hours and 28 minutes (after midday) and about 12 points (= digits) were obscured..."

- 9 February 1487 AD

  "On the 8th of February, an eclipse of the Moon occurred at about the second hour after midnight, in the morning. When the Moon began to be eclipsed, the Sun had a depression of 29 degrees. When it was the middle of the eclipse, the true time as indicated by the clock was 3 hours and 45 minutes. At the end of total obscuration, the Sun had a depression of 24 degrees, while the clock read 4 hours 18 minutes. The end of the eclipse was at 5 hours 20 minutes after midnight. The times were checked by altitudes..."

  Note: Clearly the statement that the Sun had a depression of 29° at the start of the eclipses is a misprint in the text as the computed value of the solar depression is about 44° at this instant. Presumably the solar depressions were simply obtained from the negative value of the lunar altitude.

- 10 October 1493 AD

  "On the 10th October there was an eclipse of the Sun, the start of which was between the first and second hours after midday. Its start was poorly observed, but at its end the zenith was in the first degree (*puncto*) of Capricorn, namely 4 hours and 24 minutes after midday."

- 29 July 1497 AD

  "On the 29th of July there was an eclipse of the Sun. I did not observe the start of this eclipse but the end, which was about 3 hours 24 minutes after midday, agreed with its calculated value."

- 1 March 1504 AD

  "On the morning of the 1st of March I observed an eclipse of the Moon, but I could see neither the start of the eclipse, nor totality, nor even the end of totality on account of clouds. However, I saw the end of the eclipse more completely, and I observed accurately through the Earth's shadow with an armillary; and I found that the zenith was 10 degrees in Virgo. However, according to the previous observations, the Sun at the instant was 20 degrees 7 minutes in Pisces. The R.A. at the start was therefore 80 degrees 55 minutes in Capricorn. However, the R.A. of the zenith was 307 degrees 35 minutes. Whereby the end of the eclipse was 3 hours, 6 minutes and 40 seconds after midnight. Calculation gives 3 hours 22 minutes."

[28] Once more, these translations are those published in Steele & Stephenson (1998b).

Date	Type	Contact	Object	Altitude (°) Observed	Computed	Local Time (h) Predicted	Observed	Computed
29 Jul 1478	Solar	1	Sun	54.50	55.76	-	13.09	12.78
		4	Sun	41.50	41.00	-	14.95	15.01
16 Mar 1485	Solar	1	-	-	-	-	15.43	15.47
		4	-	-	-	-	17.47	17.50
9 Feb 1487	Lunar	M	Clock	-	-	-	3.75	3.81
		3	Sun	-24.00	-24.61	-	4.44	4.38
		3	Clock	-	-	-	4.30	4.38
		4	Clock	-	-	-	5.33	5.50
10 Oct 1493	Solar	4	Zenith	-	-	-	16.40	16.49
29 Jul 1497	Solar	4	-	-	-	15.40	15.40	15.66
1 Mar 1504	Lunar	4	Zenith	-	-	3.37	3.11	2.98

Table 5.6: Eclipse observations made by Bernard Walther.

Walther's measurements of the eclipses are summarized in Table 5.6. From the Table it is evident that the typical accuracy of Walther's eclipse timings is about 0.12 hours, the same value as Regiomontanus' measurements. This is interesting as Walther preferred to measure the position of the Sun or to use a clock, rather than to measure the altitude of a bright star as Regiomontanus had done. But it would seem that the same level of accuracy was typically achieved no matter how the time was determined. However, as the clock used by Walther was probably regulated by comparison with observations of stellar or solar altitudes, this is perhaps not surprising.

On the three occasions when Walther did measure altitudes during the eclipses, he achieved a level of accuracy almost identical to that of Regiomontanus. During the period when Walther made his eclipse observations, he also made more than 700 measurements of the meridian zenith distance of the Sun. These measurements, which Kremer (1983) has shown were in all but one case made with the Ptolemaic Ruler, are accurate to about one minute of arc (Newton 1982). As with Regiomontanus' timings, it would appear that the various problems of determining the exact moment of an eclipse contact may have been the limiting factor in Walther's measurements of the time of an eclipse.

Bernard Walther's two calculations of the time of an eclipse using the *Alfonsine Tables* are of a comparable accuracy to those made by Regiomontanus.

5.4.6 Nicholas Copernicus

Nicholas Copernicus has become justly famous as one of the foremost astronomers of the European Renaissance.[29] He was born in AD 1473 at Torún in Poland to a prosperous merchant family, and following his father's death in AD 1483, was raised by his uncle, Lucas Watzenrode. In AD 1491 Copernicus entered the University of Cracow, where he developed an interest in astronomy. Five years later he was elected, through the influence of his uncle who had became the bishop of Ermland in AD 1489, as a canon of the Cathedral of Frauenberg. Officially to study canon law at the University of Bologna, but also to pursue his interest in astronomy, Copernicus travelled to Italy in AD 1496. In AD 1500, he visited Rome to lecture "on mathematics before a large audience of students and a throng of great men and experts in this branch of knowledge."[30] Whilst there, Copernicus observed the lunar eclipse on the 6th November 1500 AD, noting the time of the eclipse in his manuscript copy of Regiomontanus' *Ephemerides* (Zinner 1990).

After gaining permission from his chapter to continue his studies in Italy, Copernicus enrolled in the University of Padua in AD 1501 to study medicine. He returned shortly afterwards to Frauenberg where he was to spend the remainder of his days in the service of his chapter. In AD 1513 he constructed a roofless tower upon which he placed his astronomical instruments to act as an observatory

[29]For detailed biographical information, see Rosen (1971), Kesten (1946) and Koestler (1959: 121–224)

[30]Rheticus, *Narratio Prima*; trans. Rosen (1959: 111).

(Rosen 1971), and continued making astronomical observations. Around this time, he also wrote the first draft of his *Commentariolus*, outlining his heliocentric world system. This he circulated privately to friends in order to gain an idea of the reception his theory would receive. The response cannot have been too encouraging, for, although he commenced writing his *De Revolutionibus*, which outlined his world system in great detail, he was reluctant to publish it. It was not until Georg Joachim Rheticus, a professor of mathematics at the University of Wittenberg, visited Copernicus that he began to consider publication.

In AD 1540, Copernicus gave Rheticus permission to write an account of the *De Revolutionibus* to try to stimulate interest in his work (Swerdlow 1996). This Rheticus did in his *Narratio Prima*,[31] and its reception encouraged Copernicus to complete the *De Revolutionibus*. By May of AD 1542 the book was ready for printing in Nuremberg. However, Copernicus himself fell ill later in that same year and only received a copy of his book on the 24th May 1543 AD, the day of his death (Swerdlow 1996).

According to Rheticus in his *Narratio Prima*, Copernicus was a careful and diligent observer who, "for nearly 40 years in Italy and here in Frauenberg ... observed eclipses and the motion of the Sun."[32] Unfortunately, however, Copernicus' original observational record is lost, and only those observations he cited in his published works are extant. In his *De Revolutionibus* Copernicus records observations of five lunar eclipses that he himself observed. Following Ptolemy, he uses these observations, together with those recorded in Ptolemy's *Almagest*, to determine various parameters for his theories. As he notes, lunar eclipses are particularly useful for this purpose since they are not affected by parallax:

> "On account of them (parallaxes) the Moon's place cannot be observed by astrolabes and any other instruments whatever. But in this area too nature's kindliness has been attentive to human desires, inasmuch as the Moon's place is determined more reliably through its eclipses than through the use of instruments, and without any suspicion of error. For while the rest of the universe is bright and full of daylight, night is clearly nothing but the Earth's shadow, which extends in the shape of a cone and ends in a point. When the Moon encounters this shadow, it is darkened, and when it is immersed in the midst of the darkness it is indubitably known to have reached the place opposite the Sun. On the other hand, solar eclipses, which are caused by the interposition of the Moon (between the Earth and the Sun), do not provide precise evidence of the Moon's place. For at that time we happen to see a conjunction of the Sun and Moon which, as regards the centre of the Earth, either has already passed beyond or has not yet occurred, on account of the aforementioned parallax..."
>
> [*De Revolutionibus*, IV, 3; trans. Rosen (1978: 177–178)]

The five lunar eclipses recorded in the *De Revolutionibus* were observed on the 6th November 1500 AD, the 2nd June 1509 AD, the 6th October 1511 AD, the 5th September 1522 AD, and the 25th August 1523 AD. The first eclipse was observed in Rome during Copernicus' lecture visit. The remaining eclipses were observed in Frauenberg. Copernicus notes that Frauenberg is at the same longitude as Cracow; in truth, Frauenberg is about $\frac{1}{4}^{\circ}$ to the west. As an example of Copernicus' eclipse records, I quote below a translation of the account of the observation of the eclipse in AD 1511:

> "Following his (Ptolemy's) example, let me now proceed to the second set of three lunar eclipses, which I observed very carefully like him. The first one occurred at the end of 6 October 1511 AD. The Moon began to be eclipsed $1\frac{1}{8}$ uniform hours before midnight, and was fully illuminated again $2\frac{1}{3}$ hours after midnight. Thus, the middle of the eclipse was $\frac{7}{12}$ of an hour after the midnight followed by 7 October = the Nones of October. This was a total eclipse of the Moon..."
>
> [*De Revolutionibus*, IV, 5; trans. Rosen (1978: 188)]

[31] The *Narratio Prima* has been translated, along with the *Commentariolus*, by Rosen (1959).

[32] *Narratio Prima*; trans. Rosen (1959: 125).

			Local Time (h)	
Date	Type	Contact	Observed	Computed
1500 Nov 6	Lunar	M	2.00	1.83
1509 Jun 2	Lunar	M	23.75	23.77
1511 Oct 6	Lunar	1	22.88	22.62
		4	2.33	1.78
1522 Sep 5	Lunar	1	23.60	23.46
		M	1.33	1.19
1523 Aug 25	Lunar	1	2.80	2.39

Table 5.7: Eclipse observations made by Nicholas Copernicus.

It is not known how Copernicus made his time measurements. He may have either used a clock or have measured the altitude of the Moon or a clock-star at the time of the eclipse.

Copernicus' eclipse observations are summarized in Table 5.7. It is immediately clear from this Table that, with the exception of the observation in AD 1509, all of Copernicus' observed times are slightly late. This suggests that Copernicus did not detect the apparent moment of an eclipse contact until some time after the true moment of this contact, and, furthermore, that he made no allowance for the difference between true and apparent contacts. The mean accuracy of these observations is about 0.21 hours, which is quite poor in comparison with that of his predecessors, Regiomontanus and Walther.

5.4.7 Tycho Brahe

Born into a Noble family in AD 1546, Tycho Brahe spent most of his adult life engaged in astronomical observation.[33] Tycho was brought up by his paternal uncle who ensured that, from the age of seven, he was educated in Latin and the preparatory subjects. Between AD 1559 and AD 1562 he attended the Lutheran University of Copenhagen where he studied the *quadrivium*.[34] By AD 1560, Tycho had developed an interest in astronomy, and, following his sighting of a partial solar eclipse in August of that year, began making astronomical observations. The young Tycho's growing interest in science was a worry to his uncle, who decided in AD 1562 to send him to the University of Leipzig to study law. However, Tycho's interest could not be overcome, and he continued to make astronomical observations in secret (Hellman 1970).

After he left Leipzig in AD 1565, Tycho spent the next eight years travelling throughout northern Europe, visiting various men who were interested in astronomy, and lecturing on astronomy in a number of universities. Then, on the 11th November 1572 AD, Tycho noticed a new star shining brightly in the constellation of Cassiopeia (Clark & Stephenson 1977). This observation was to result in Tycho abandoning the notion of the fixed stars as being immutable objects, and, together with his later cometary observations, led him to reject the Aristotelian cosmology of the crystalline spheres. In AD 1573, Tycho published a short tract on the new star, which, along with the details of his observations of the star, also included a section of its astrological significance, and predictions for a lunar eclipse on the 8th December of that year. These predictions he had made himself by adapting the *Prutenic Tables* of Reinhold. The following year, Tycho observed this same eclipse, noting with considerable satisfaction the accuracy of his earlier predictions:

> "I carefully observed the eclipse from the Senate House in Knudstrup, for the sky was sufficiently clear. I had the help of my beloved sister Sophie Brahe, at that time a girl of 14, who was a willing and competent assistant. Indeed, by means of the ungilded brass Quadrant, with which a single degree could sufficiently readily be measured, we saw that the Moon entered the shadow and

[33] For detailed biographical information, see Hellman (1970), Dreyer (1890) and Thoren (1990).

[34] Arithmetic, geometry, music, and astronomy.

when (only) a small part was covered, the Head of the Lower Twin (β Gem) was at an altitude of $14\frac{1}{2}^o$, so that the star was scarcely 14^o above the horizon at the beginning. Our value was higher than the same star's height given by earlier calculations of 13^o. But this was only a small difference with the observation. At the beginning of totality, we observed that the same star had an altitude of $22\frac{2}{3}^o$. Our earlier calculations put this at $21\frac{1}{2}^o$. That is also only a moderate difference. At the beginning of the departure and shining forth from the shadow, Canis Minor (α CMi) was observed to have an altitude of $17\frac{5}{6}^o$. But the earlier (calculated) value was 17^o, which is hardly any noticeable difference. Near the very end of the whole eclipse, no stars were observed, for from the time when about half of the Moon had left the Earth's shadow, all the way until the complete end and beyond, thin clouds veiled the sky, and the Moon was not discernable. On the other hand, when its disk reached an altitude of around 50^o 25', its whole light was seen to be recovered, as much as could be discerned through the gaps in the clouds. However, the final observation was not sufficiently accurate, in part because the Moon was in clouds, as mentioned, and partly because it was approaching the south and so the altitude scarcely changed with time. The aforementioned observations agree sufficiently well with the earlier (calculation). For the last altitude observation is only about 1^o higher, which is tolerable. Indeed, perhaps as little as 5 minutes of time lacked (in comparison with calculation) at the Royal City of Knudstropium Haffnia, or rather more assuming a place with a longitude to the east, so this requires virtually no correction. And, for myself, I cannot but be very surprised that even at this youthful age of 26 years, and without many accurate observations of the motion of the luminaries, I was able to get such accurate results. Indeed nothing was changed, and my observations of the heavens were fully reported in the book in which annual observations were recorded; they were easily written by my sister using the light of a lantern."

[*Opera Omnia*, X, 38–39]

Tycho had good reason to be proud of the accuracy of his predictions. For example, the computed altitude of β Geminorum at the star of the eclipse is 13.19°, very close to his predicted 13°, and at second contact is 20.72°, once more close to his predicted $21\frac{1}{2}^o$.

In AD 1575, Tycho visited William IV in Kassel. William was also very interested in astronomy, and it was possibly on his recommendation that in the following year, King Frederick II offered Tycho the island of Hven and asked him to construct an astronomical observatory there. Within a few months Tycho had established himself on the island, and construction began on his new home and observatory, which he named "Uraniborg". He equipped this observatory with a wide range of astronomical instruments, although many of these would be replaced in the following years in his search for ever greater accuracy (Thoren 1973). Tycho later published a description of the instruments in the Uraniborg observatory entitled *Astronomiae Instauratae Mechanica*. This has been translated into English by Raeder, Strömgren, & Strömgren (1946).

Over the next twenty years on Hven, Tycho made many thousands of observations of stars, planets, the Sun and Moon, and eclipses. These observations, in particular those of the planet Mars, were later to be extensively used by Kepler in formulating his laws of planetary motion. However, very few of these observations were published at the time, and it was not until J. L. E. Dreyer collected and published transcriptions of all of Tycho's known manuscripts in *Tychonis Brahe Dani Opera Omnia* that the full extent of Tycho's observational activity became known.[35] It should be noted that in recording the date of his observations, Tycho continued to use the Julian calendar up until AD 1599, seventeen years after it had generally been replaced by the Gregorian calendar in Denmark. The reason for this is not known, for he does not seem to have had any practical or theological objections to the Gregorian calendar (Hellman 1970). It is possible that continuity of dates made comparison of observation and calculation easier.

Among Tycho's many observations made on Hven are more than thirty of solar and lunar eclipses. However, his observational accounts of many of these eclipses are difficult to evaluate — many consist simply of sketches of the eclipsed luminary made at specific times during the eclipse, rather than

[35] Four volumes of this collection are filled with Tycho's observations (Dreyer 1923, 1924, 1925, 1926).

Date	Type	Contact	Local Time (h) Observed	Computed
1573 Dec 8	Lunar	1	18.33	18.22
		2	19.45	19.21
		3	21.00	20.78
1577 Apr 2	Lunar	1	19.08	19.18
		2	20.17	20.16
		3	21.67	21.72
		4	22.75	22.70
1577 Sep 26	Lunar	3	1.93	2.09
1578 Sep 15	Lunar	1	0.41	0.44
		2	2.17	2.19
1579 Feb 25	Solar	1	16.73	16.91
		4	18.77	18.80
1581 Jan 19	Lunar	1	19.98	20.10
		2	21.30	21.28
		3	22.67	22.71
1584 May 10	Solar	1	5.03	5.07
		4	6.35	6.38
1588 Feb 26	Solar	1	13.50	13.48
		4	14.87	14.98
1588 Mar 12	Lunar	1	1.26	1.28
		2	2.51	2.35
		3	3.67	3.74
1590 Jul 31	Solar	1	6.83	6.81
		4	9.00	9.05
1591 Jul 20	Solar	1	14.90	14.72
		4	16.39	16.34
1600 Jul 10	Solar	1	12.72	12.49
		4	14.66	14.76

Table 5.8: Eclipse observations made by Tycho Brahe.

measurements of the time of the various eclipse contacts. Nevertheless, there are ten eclipse observations which do include timings of the contacts. In many cases it is not known how these timings were made. Sometimes Tycho measured the altitude of a clock star using either his giant mural quadrant or a smaller device, at other times he used a mechanical clock. Indeed it is likely that in many cases he used more than one method. For example, he timed the beginning of clearing of the lunar eclipse on the 26th September 1577 AD both by using a clock and by measuring the azimuth of the star α Orion:

> "I observed a total eclipse of the Moon; the beginning and middle of which could not be seen on account of clouds. However the beginning of clearing was at 1 hour 56 minutes after midnight according to a clock corrected by the Sun which showed single minutes; moreover (at this time) the bright star in the right shoulder of Orion (α Ori) was carefully measured to be $47\frac{2}{3}^\circ$ along the horizon according to careful observation. When a third of the Moon had recovered its light, the same star had moved to a direction of $32\frac{5}{6}^\circ$ from the meridian along the horizon towards the east. From observation of the star in Orion, the time the shadow left was 2 hours 10 minutes after midnight, but in this I place little faith. Note: the observation by the shoulder of Orion is not very good. In fact errors of more than 2° may be on account of a not very well derived meridian line, and also may be caused by the wood of the instrument. I prefer to trust the clock."
>
> [*Opera Omnia*, X, 50]

In years following the death of King Frederick II, Tycho gradually lost his popularity in court, particularly with the young King Christian IV who did not see the value of Tycho's astronomical observations (Hellman 1970). By AD 1597, Tycho's unpopularity had reached such a level that he decided to leave Denmark. During the next three years he once again travelled through northern Europe, looking for a patron interested in his work. Finally, in AD 1600, he settled in Prague where he was granted some financial support from the emperor. He began to observe again — his observations

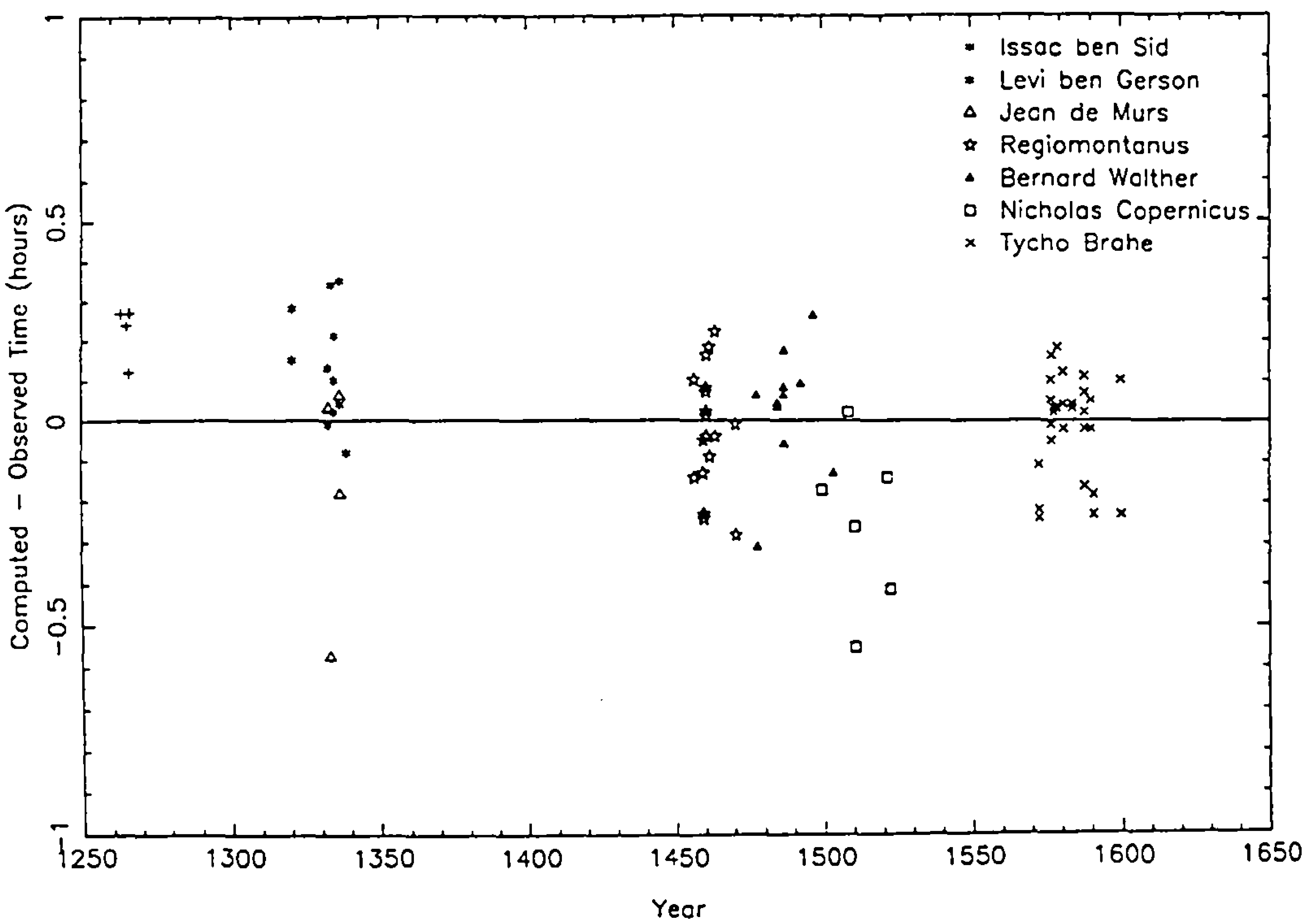


Figure 5.2: The error in the observed eclipse times.

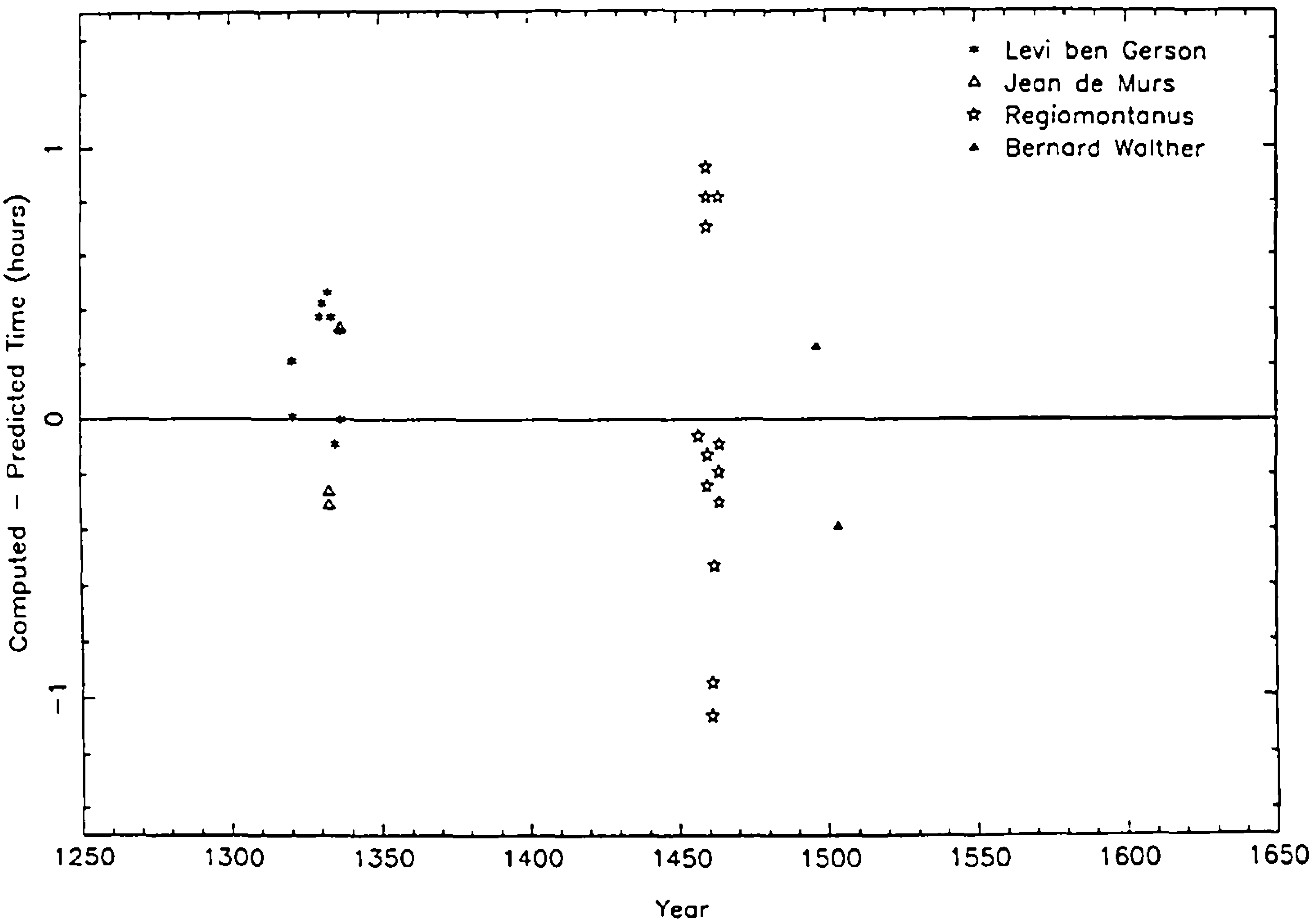
during this period include the solar eclipse on the 10th July 1600 AD — but died in the following year after a short illness.

The eclipse observations made by Tycho from which a contact time can be derived are summarized in Table 5.8. Clearly, Tycho's observations, in particular those made on Hven, are very accurate. The mean accuracy of the whole set of timings is about 0.09 hours, improving to about 0.07 hours when the eclipse in AD 1573 (observed in Knudstrup) and the eclipse in AD 1600 (observed in Prague) are ignored. Tycho often expressed considerable confidence in the accuracy of his instruments. This confidence has been shown by Wesley (1978) to have been fully justified — his angular measurements of stellar positions are typically accurate to better than 1 minute of arc. This would typically translate into an error in the time of an observation of only a fraction of a minute. Thus, it would seem that the accuracy of Tycho's eclipse timings was not limited by his ability to measure the altitude of a clock-star, if he was using this method, but rather by the difficulties of determining the exact moment of an eclipse contact.

5.5 Accuracy of the Observed and Predicted Times

The errors in the observed time of all of the eclipses observed by Later Medieval and Renaissance European astronomers are shown in Figure 5.2. The typical accuracy of these observations ranges from about 6 to 12 minutes. Unsurprisingly, given his reputation, Tycho's observations are the most accurate of the seven sets of data. However, the observations by Regiomontanus and Walther are only marginally less accurate, implying that these two astronomers also took great care over their observations.

Figure 5.3 shows the true and computed errors in the eclipse times predicted by Levi ben Gerson, Jean de Murs, Regiomontanus and Bernard Walther. The predictions made by Isaac ben Sid using the



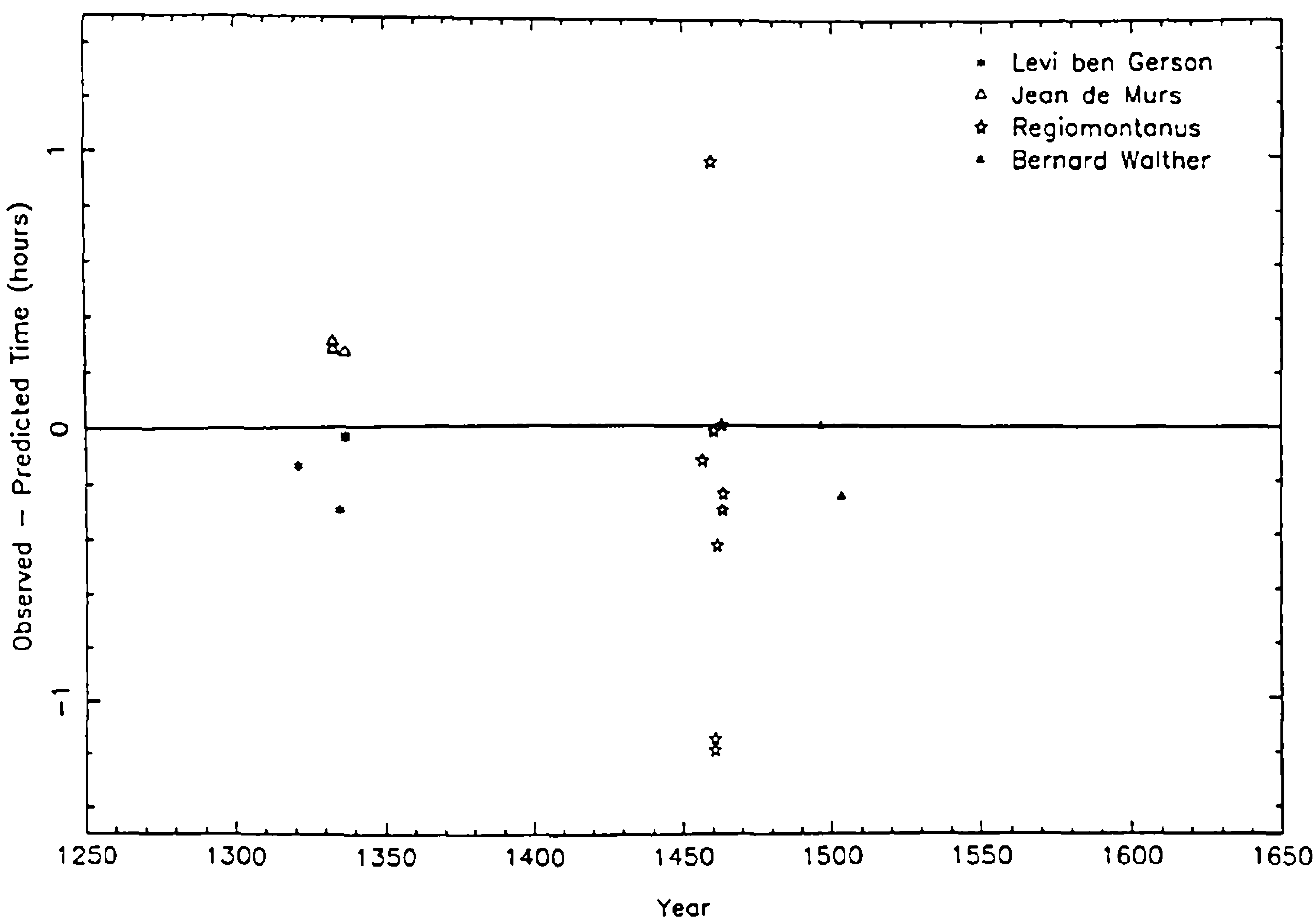


Figure 5.3: The true (above) and observed (below) errors in the predicted eclipse times.

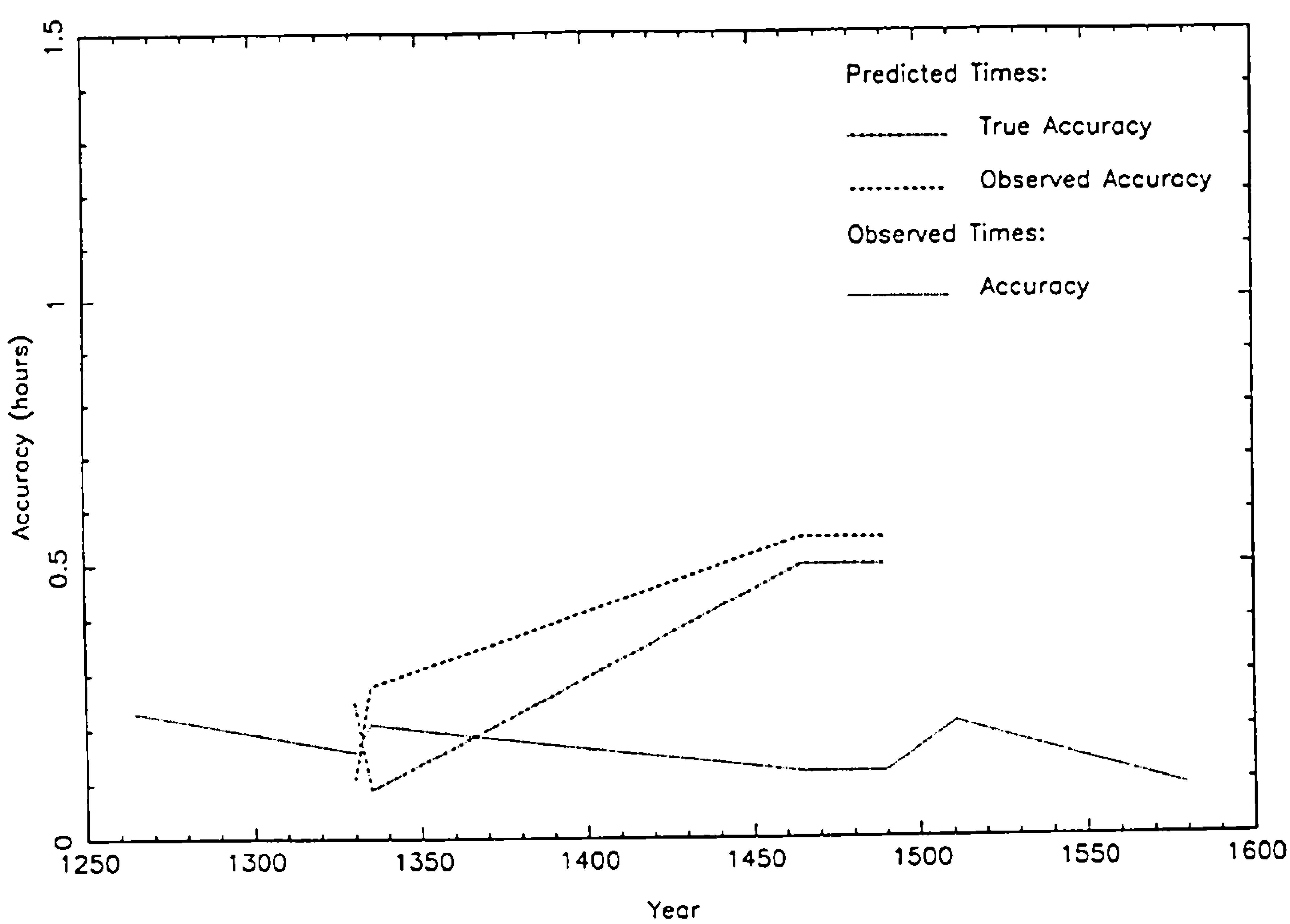


Figure 5.4: Schematic representation of the accuracy of the eclipse times.

Toledan Tables are not included since they are of significantly poorer quality to the others — perhaps as much as six times less accurate. Thus Isaac ben Sid had good reason to compile the *Alfonsine Tables* as a replacement. The typical accuracy of the various sets of observations and predictions is shown schematically in Figure 5.4. Once again I must stress that this type of diagram simply shows the general trend in the accuracy of predictions down the centuries; the lines should not be taken to imply any form of linear increase, or indeed decrease, between any two points.

The *Alfonsine Tables* were used by Jean de Murs, Regiomontanus and Bernard Walther in making their predictions. It is clear from Figure 5.4 that de Murs' predictions are significantly more successful than those by Regiomontanus and Walther. This may have been caused by a number of factors. First, de Murs' predictions were made at a time much nearer to the epoch of the tables; by the time Regiomontanus and Walther made theirs, there may have been a considerable cumulative error in the calculations due to small inaccuracies in the parameters used. Another reason may be due to the problems of determining the geographical coordinates of the sites for which the predictions were made. For example, Regiomontanus himself notes in the report of the eclipse on the 17th December 1461 AD, that the latitude of Rome is not agreed upon by all scholars. Errors in longitude were probably more serious. Kremer & Dobrzycki (1998) have made a study of a number of Alfonsine texts and found a number of varying coordinates of cities in different sources. It may be that Regiomontanus and Walther used longitudes that were inaccurate, but that de Murs' value was quite good. Finally, the predictions made by de Murs were based upon the Castilian version of the *Alfonsine Tables*, whereas those by Regiomontanus and Walther were made using the Latin version of the tables. If Poulle (1988) is correct in claiming that Jean de Murs compiled the Latin version himself, then it is possible, if unlikely, that his tables were actually less accurate than those he sought to replace.

Part III

The Eastern Heritage

Chapter 6

China (c. AD 400 – 1600)

Probably another reason why many Europeans consider the Chinese such barbarians is on account of the support they give to their Astronomers — people regarded by our cultivated Western mortals as completely useless. Yet there they rank with Heads of Departments and Secretaries of State. What frightful barbarism!

— Franz Kühnert, Vienna, 1888

6.1 Introduction

China has the longest astronomical heritage of any country in the world. Systematic astronomical records began in the eighth century BC and continue more or less uninterrupted up to the present day. Whilst astronomy in Babylon, the only other great civilization in the ancient world from which a vast array of astronomical records is preserved, had more or less ceased by the first century AD, the traditional astronomy of China continued up until the start of the present century. That is not to say that astronomy in China was not influenced at times by other cultures. For example, during the Yuan dynasty, many Islamic astronomers were invited to the Chinese capital, and an Islamic Observatory was set up (Yabuuti & van Dalen 1997). More significantly, when the Jesuits came to China in the seventeenth century AD they brought with them western astronomical knowledge with which they helped to reform the Chinese calendar (d'Elia 1960; Bernard 1973). However, throughout all of this, Chinese astronomy retained a character all of its own. Furthermore, it was to be at the root of all of the astronomy which was to develop in the two other great ancient and medieval cultures of East Asia, Japan and Korea.

As Needham (1974) has noted, astronomy in China differed from that in the western world in two important respects: it was polar rather than ecliptic, and it was primarily an activity of the bureaucratic state rather than of priests or scholars. The former, which led to far earlier mechanization of celestial models than in the west (Needham 1974), will not be of great concern to us here. But the second factor, that is the official nature of astronomy in China, will feature repeatedly throughout this study.

In China, the emperor had the ultimate responsibility for the rule of government. But it was believed that he only ruled under the mandate of Heaven, and if Heaven was displeased with his rule, it would send a sign. These signs could take a number of forms such as diseases, floods, earthquakes, or, often, unusual events in the day- or night-sky. Because of this, the Astronomical Bureau, headed by an Astronomer Royal, was one of the most important and secretive governmental institutions. Its purpose was to observe and interpret any celestial events for the emperor. Furthermore, the Astronomical Bureau, or sometimes a separate Calendar Bureau, was responsible for maintaining the calendar, for making predictions of forthcoming astronomical events, and for the maintenance of the water clocks. The size structure of the Astronomical Bureau varied from dynasty to dynasty. For example, during the Ming it was comprised of 43 members (Ho 1970), whereas during the T'ang, there were more than 80, plus over 300 clerks and 500 students (Nakayama 1969: 18–19)

I shall begin this chapter with some necessary historical details, followed by a discussion of calendrical astronomy in China, the units of time and the methods of time measurement used in China. I shall then discuss the available records of timed eclipse observations and predictions in pre-Jesuit Chinese history, drawing a number of conclusions on their accuracy. Much of the following discussion is based upon my published articles, Steele & Stephenson (1998a) and Steele (1998d).

6.2 Historical Outline

The history of China emerges from the legendary period around the middle of the second millennium BC. These legends, which were written down by Ssu-ma Ch'ien in his *Shih-chi* or *Historical Records*, tell of a Hsia dynasty which dated back to the middle of the third millennium BC. However, there are no contemporary records of any sort from this period. Indeed, it is not until the Shang dynasty, the supposed successor of the Hsia, that there is any direct evidence for the existence of a dynasty. This has been found on the so called "oracle bones" from what is believed to be Yin (the last capital of the Shang dynasty) near An-yang in north-eastern China. These were first recovered at the end of the last century (Needham 1954). The oracle bones were used for divination, a record of which would then be inscribed onto the bone in a primitive script, and contain allusions to historical, meteorological and astronomical events.

During the eleventh century BC, the Shang dynasty was overthrown by the Chou dynasty. This dynasty was to rule China amid growing unrest until the end of the eighth century BC, when a number of feudal semi-independent states grew up which paid little allegiance to the Chou King. This situation continued until 221 BC, first with the various states living in a state of relative harmony during the *Ch'un-ch'iu* or "Spring and Autumn" period, but later, during the *Chan-kuo* or "Warring States" period, with the states constantly at war with one another. However, in 221 BC, the Ch'in ruler succeeded in unifying the whole country, and adopted the title Shih Huang-ti or "First Sovereign Emperor." It was during his rule that the system of bureaucratic government that was to form the basis of all subsequent Chinese history was set up (Needham 1954). After Shih Huang-ti's death, his son became Emperor; however, he was a weak leader and was soon overthrown by Liu Pang, the founder of the Han dynasty.

The Han dynasty was to last for nearly four hundred years, with only a brief interregnum between AD 9 and AD 23, when Wang Mang, a former chief minister to the Emperor, seized control of the country. However, following his assassination in AD 23, Liu Hsiu, a relative of the rulers of the former Han dynasty, regained control and started the Later (*Hou-*) Han dynasty. Han society was characterised by being a slightly less harsh version of the bureaucratic system of government developed in the Ch'in dynasty, and also by a great interest in science. However, towards the end of the Later Han period, political machinations became rife, and after the suppression of a peasant revolt in AD 184, by AD 220 the central government could no longer be sustained.

China then entered another period of division, known as the *San-kuo* or "Three Kingdoms" period. Three states, Wu in the south-east, Shu in the south-west, and Wei in the north, all fought for supremacy over the one another. Gradually Wei overcame the other two states, and in AD 265 Ssu-ma Yen, a Wei general, founded the Chin dynasty. However, China was at this time under constant attack from a variety of tribes from the north, and by AD 317, Chin rule had been restricted to the southern part of China. Once more, China became divided: this time into northern and southern states. This period is known as *Nan-pei*. In the south, the Chin dynasty was succeeded in rapid succession by the Liu-Sung, the Ch'i, the Liang, and the Ch'en. In the north, the Northern Wei ruled for nearly one hundred and fifty years. This dynasty was followed in quick succession by the Eastern Wei, the Northern Chi, the Western Wei, and the Northern Chou.

After a period of nearly four hundred years of almost constant division, China was once again unified by the Sui dynasty. This dynasty was only to last for 26 years, for in AD 618 it was replaced by the T'ang dynasty. The T'ang dynasty was one of the most successful dynasties in the history of

China, lasting for nearly three hundred years. The extent of China's territories and influence were expanded back to the levels of the Han dynasty and then beyond into Tibet and Korea. T'ang society was characterised by being one of the most productive in works of literature and art.

From the end of AD 755 to the beginning of AD 763, T'ang government in China was threatened by rebellion. This was led by An Lu-shan, the military governor of the northern P'ing-lu and Fan-yang provinces. Between AD 755 and AD 757, the rebels achieved considerable success, occupying both Lo-yang and the capital Ch'ang-an. Sadly, the rebels expressed little interest in Ch'ang-an and this led to much historical material being lost. Over the next five years the T'ang government began to regain control, and by the beginning of AD 763 the rebellion had been quashed.

The T'ang dynasty finally fell in AD 907 and over the next fifty years there followed a period known as the *Wu-tai* or "Five Dynasties" in which five short lived dynasties ruled the country. However, many other small independent states were also active. Most important among these was the semi-nomadic Liao kingdom. In AD 960, the Sung dynasty came to power, setting up its capital at Pien. Initially at peace with its neighbours, in AD 1127 the northern half of China was lost to the Jurchen, who had established the Chin dynasty in AD 1115. The Sung fled south, establishing themselves at Lin-an, their new capital. The Sung dynasty was period of great scientific and technological achievement in China. In the words of Needham (1954: 134), "whenever one follows up any specific piece of scientific or technological history in Chinese literature, it is always at the Sung dynasty that one finds the major focal point."

The original capital of the Chin dynasty was Shang-ching in Manchuria, but this was replaced in AD 1153 by Yen, and then sixty-one years later by Pien. The Chin dynasty in northern China was extinguished by the Mongols in AD 1234. The Mongol emperor Kubilai Khan established the Yuan dynasty in AD 1259, and moved his capital from Karakorum in Mongolia to Ta-tu in AD 1264. In AD 1276, the Yuan moved down into southern China and brought to an end the Sung dynasty. For the next hundred years, the Yuan dynasty controlled China, but by AD 1369, the indigenous Ming dynasty had overthrown the Mongols and regained control of the country. The Ming dynasty saw a great decline in interest in science in China. This was in part caused by a wish to return to a more traditional way of life, including a return to more traditional types of technology.

By the middle of the seventeenth century, the Ming dynasty had been overthrown by rebels from Manchuria who formed the Ch'ing dynasty. European Jesuits, who had been visiting China since the end of the sixteenth century, now began to bring western astronomical theories and instruments to China, and the traditional astronomical practices began to disappear. Further discussion of the influence of the Jesuits on Chinese astronomy is beyond the scope of this study.

The various dynasties that have ruled China over the last three thousand years are listed in Table 6.1. The imperial capital has been changed many times in the history of China. Often this occurred when a new dynasty came to power, but in some cases, for example during the T'ang dynasty, the capital was moved for other reasons. The capital cities adopted at the various times are also shown in Table 6.1.

6.3 Sources of Astronomical Records in Chinese History

The earliest astronomical references in Chinese history are contained on the Shang dynasty oracle bones (Xu, Yau & Stephenson 1989; Xu, Stephenson & Jiang 1995). These relics, which were first discovered near An-yang, consist of animal bones and turtle shells inscribed with a primitive form of Chinese characters. Many hundreds of thousands of these bones have so far been uncovered, a small number of which contain allusions to astronomical events such as observations of eclipses, comets, and planets. However, generally it is not possible to date the observations contained on the oracle bones, and so they provide little scope for detailed analysis.

Written history in China effectively starts with an ancient chronicle known as the *ch'un-ch'iu*, or *Spring and Autumn Annals*. It is the only surviving example of the ancient state chronicles of

Dynasty	Rise	Fall	Capital City	Latitude (°)	Longitude (°)
Shang	c. -1500	c. -1045	Yin	36.06	-108.88
Western Chou	c. -1045	-700	Hao	34.16	-108.71
Eastern Chou	-769	-255	Lo-i	34.75	-112.50
Lu state[1]	-721	-480	Ch'u-fu	35.66	-117.01
Ch'in	-254	-205	Hsien-yang	34.38	-108.85
Former Han	-204	+9	Ch'ang-an	34.35	-108.88
Hsin	+9	+25	Ch'ang-an	34.35	-108.88
Later Han	+26	+190	Lo-yang	34.75	-112.47
	+191	+196	Ch'ang-an	34.35	-108.88
	+197	+220	Hsu-chang	34.05	-113.80
Wu[2]	+221	+280	Chien-k'ang	32.03	-118.78
Shu[2]	+221	+264	Ch'eng-tu	30.61	-104.10
Wei[2]	+221	+265	Lo-yang	34.75	-112.47
Western Chin	+265	+312	Lo-yang	34.75	-112.47
	+312	+317	Ch'ang-an	34.35	-108.88
Eastern Chin	+317	+420	Chien-k'ang	32.03	-118.78
Liu-Sung[3]	+420	+479	Chien-k'ang	32.03	-118.78
Ch'i[3]	+479	+502	Chien-k'ang	32.03	-118.78
Liang[3]	+502	+557	Chien-k'ang	32.03	-118.78
Ch'en[3]	+557	+588	Chien-k'ang	32.03	-118.78
Northern Wei[4]	+398	+493	P'ing-ch'eng	40.20	-113.20
	+493	+534	Lo-yang	34.75	-112.47
Eastern Wei[4]	+534	+550	Yeh	36.31	-114.55
Northern Chi[4]	+550	+557	Yeh	36.31	-114.55
Western Wei[4]	+534	+556	Ch'ang-an	34.35	-108.88
Northern Chou[4]	+556	+581	Ch'ang-an	34.35	-108.88
Sui	+581	+583	Ch'ang-an	34.35	-108.88
	+583	+617	Ta-hsing Ch'eng	34.27	-108.90
	+607	+617	Lo-yang[5]	34.75	-112.47
T'ang	+618	+682	Ch'ang-an	34.27	-108.90
	+682	+701	Lo-yang	34.75	-112.47
	+701	+717	Ch'ang-an	34.27	-108.90
	+717	+718	Lo-yang	34.75	-112.47
	+718	+722	Ch'ang-an	34.27	-108.90
	+722	+723	Lo-yang	34.75	-112.47
	+723	+724	Ch'ang-an	34.27	-108.90
	+724	+727	Lo-yang	34.75	-112.47
	+727	+731	Ch'ang-an	34.27	-108.90
	+731	+732	Lo-yang	34.75	-112.47
	+732	+734	Ch'ang-an	34.27	-108.90
	+734	+736	Lo-yang	34.75	-112.47
	+736	+881	Ch'ang-an	34.27	-108.90
	+881	+885	Ch'eng-tu	30.61	-104.10
	+885	+904	Ch'ang-an	34.27	-108.90
	+904	+907	Lo-yang	34.75	-112.47
Later Liang[6]	+907	+923	Pien	34.78	-114.33
Later T'ang[6]	+924	+936	Lo-yang	34.75	-112.47
Later Chin[6]	+936	+946	Pien	34.78	-114.33
Later Han[6]	+946	+950	Pien	34.78	-114.33
Later Chou[6]	+950	+960	Pien	34.78	-114.33
Sung	+960	+1127	Pien	34.78	-114.33
	+1127	+1276	Lin-an	30.25	-120.17
Chin	+1115	+1153	Shang-ching	45.50	-127.00
	+1153	+1214	Yen	39.92	-116.42
	+1214	+1234	Pien	34.78	-114.33
Yuan	+1264	+1368	Ta-tu	39.92	-116.42
Ming	+1369	+1420	Ying-t'ien	32.03	-118.78
	+1421	+1644	Pei-ching	39.92	-116.42
Ch'ing	+1644		Pei-ching	39.92	-116.42

1. Ch'un-ch'iu period.
2. San-kuo period.
3. Nan-pei period: Southern dynasties.
4. Nan-pei period: Northern dynasties.
5. Loyang acted as an second eastern capital during this period.
6. Wu-tai period.

Table 6.1: Chinese dynasties and their capital cities.

China, the others having been lost, possibly in the infamous "Burning of the Books" by Emperor Shih Huang-ti in 213 BC. The escape of the *ch'un-ch'iu* from this fate may be due to the fact that the work was attributed to Confucius, although the compiler of the work is not named in the text. The Chinese characters already in use at this period continued virtually unchanged until the the middle of the present century when a number of simplified characters were introduced.

The *ch'un-ch'iu* contains a detailed record of the state of Lu over the period 722–481 BC. A short supplement to the work continues the records down to 468 BC. The *ch'un-ch'iu* contains accounts of a number of celestial phenomena, together with historical events such as the accession or death of a ruler, or details of a war with a neighbouring state, all in chronological order. The astronomical records include a series of 37 solar eclipse observations, two reports of meteors, and four references to comets (Stephenson & Yau 1992).

There are few other references to astronomical events in Chinese history until the Han dynasty. From this period on, the dynastic histories are our main source of astronomical records. These histories were compiled after the fall of a dynasty, sometimes by officials of the succeeding dynasty and at other times privately. 25 of these histories have been authorized as official histories. In addition, a history of the Ch'ing dynasty, the *Ch'ing-shih-kao* was completed in 1927. However, this work has not yet been approved by the government and so must be regarded only as a draft history. Nevertheless, this work continues the tradition of the earlier dynastic histories, and so is often considered in the same light as the earlier works.

The earliest dynastic history is Ssu-ma Ch'ien's *Shih-chi*. This work details the history of China from earliest times down to the Former Han dynasty. The *Shih-chi* may be split into five divisions — *Pen-chi*, annals of the emperors, *Shih-chia*, details of the noble families, *Piao*, chronological tables, *Lieh-chuan*, biographies, and *Chih*, treatises (Han 1955). The annals of the emperors detail, in chronological order, important affairs of state, with a particular reference to the emperors. The section on the noble families contains a genealogical register of the various important nobles. The chronological tables provide a brief outline of historical events. The biographies are the longest part of the history. As their name suggests, they give detailed biographical information on a number of important people such as scholars and officials. Finally, a number of treatises are included on various aspects of human life. These include: *Li*, the calendar, *Yueh*, Music, and *T'ien-wen*, astrology.[1]

The later dynastic histories all followed the general format of the *Shih-chi*, although in many cases the section dealing with the noble families, and on occasions also the chronological tables or the treatises, were omitted. Furthermore, the range of subjects covered by the treatises also varied from dynasty to dynasty. For example. although an astrological treatise was included in most of the histories, a treatise on the civil service was only included in some of the more recent works.

The 26 dynastic histories are listed in Table 6.2, along with their date of composition and name of their editor. In many cases, the Bureau of Historiography was charged with compiling the histories, and so the name of the director of the Bureau is given. Occasionally, later historians would compile new histories of a particular dynasty if they did not consider the present history to be adequate. If this new history was officially adopted it would become known as the *Hsin* or "New" history of the dynasty, and the original version would become the *Chiu* or "Old" history of the dynasty. For example, the *T'ang-shu* was replaced in the middle of the eleventh century AD by the *Hsin T'ang-shu* and became known as the *Chiu T'ang-shu*. Both versions are still available and are of interest. For instance, the *Chiu T'ang-shu* contains some interesting astronomical records that are absent from the *Hsin T'ang-shu*.

The dynastic histories contain many references to celestial events. These are found predominantly in the astrological, calendrical and five-element treatises, although there are a small number of astronomical observations reported in the annals on the emperors. It is interesting to note the different styles in which astronomical events are described in these various sources. For example, astronomi-

[1]In modern Chinese usage, *T'ien-wen* means astronomy, but in the context of early Chinese history, it is more accurate to translate the term as astrology.

History	Editor	Date of Compilation
Shih-chi	Ssu-ma Ch'ien	104–87 BC
Han-shu	Pan Ku	AD 58–76
Hou-han-shu	Fan Yeh	c. AD 420
San-kuo-chih	Ch'en Shou	AD 285–297
Chin-shu	Fang Hsuan-ling	AD 644
Sung-shu	Shen Yueh	AD 492–493
Nan-Ch'i-shu	Hsiao Tzu-hsien	c. AD 500
Liang-shu	Yao Ssu-lien	AD 628–635
Ch'en-shu	Yao-Ssu-lien	AD 622–629
Wei-shu	Wei Shou	AD 551–554
Pei-Ch'i-shu	Li Po-yao	AD 627–636
Chou-shu	Ling-hu Te-fen	c. AD 620
Nan-shih	Li Yen-shou	AD 630–650
Pei-shih	Li Yen-shou	AD 630–650
Sui-shu	Wei Cheng	AD 629–636
Chiu T'ang-shu	Liu Hsu	AD 940–945
Hsin T'ang-shu	O-yang Hsiu & Sung Ch'i	AD 1043–1060
Chiu Wu-tai-shih	Hsueh Chu-cheng	AD 973–974
Hsin Wu-tai-shih	O-yang Hsiu	AD 1044-1060
Sung-shih	T'o T'o	AD 1343–1345
Liao-shih	T'o T'o	AD 1343–1344
Chin-shih	T'o T'o	AD 1343–1344
Yuan-shih	Sung-Lien	c. AD 1350
Hsin Yuan-shih	K'o Shao-min	AD 1890–1920
Ming-shih	Chang T'ing-yu	AD 1678–1739
Ch'ing-shih-kao	K'o Shao-min	AD 1914–1927

Table 6.2: The 26 Dynastic Histories.

cal observations in the annals tend to be very brief, merely noting the occurrence of the event, as is illustrated by an account of the comet seen in 138 BC:

> "(The Emperor) granted to those who moved to Mou-ling two hundred thousand cash to each household and two hundred *mou* of land, and for the first time the Pien Gate Bridge was built. In the autumn, the seventh month, there was a comet in the north-east. The King of Chi-ch'uan, (Liu) Ming, was sentenced for killing his Grand Tutor and Palace Tutor. He was dismissed and exiled to Fang-ling..."
>
> [*Han-shu*, 6; trans. Dubs (1944: 31–32)]

In comparison, the astrological treatises often give both a detailed account of the observation and an astrological interpretation of the event. For example, a record of a comet in AD 349 gives details of its appearance and then connects the observation with war and sickness in the land:

> "On a *chi-mao* day in the eleventh month of the 5th year of the *Yung-Ho* reign-period of (Emperor) Mu Ti a white *Hui* comet measuring 1 *chang* appeared within *K'ang*, with its rays pointing towards the west. On a *ting-ch'ou* day in the first month of the 6th year a *Hui* comet again appeared at *K'ang*. According to the standard prognostication this presaged war and death and also sicknesses and and epidemics. During the eighth month of the 5th year Ch'u P'ou embarked upon the northern campaign, but suffered a great setback. During the eleventh month Jan Min executed Shih Tsun and also put to death more than a hundred thousand men of the Hu border tribes, while the central region (of the empire) was in a state of emergency. During the twelfth month Ch'u P'ou died. A wide-spread epidemic also prevailed during the year."
>
> [*Chin-shu*, 13; trans. Ho (1966: 241)]

A wide variety of astronomical phenomena are reported in the dynastic histories. These range from predictable events such as the positions of planets and the occurrence of eclipses, to observations of less frequent events such as sunspots, aurorae, "new stars", and comets.

A relatively small number of astronomical records may also be found in sources other than the dynastic histories. For example, the *Wen-hsien T'ung-k'ao* or *Comprehensive History of Civilization*, which was compiled in AD 1307 by Ma Tuan-lin, contains a section devoted to astronomical observations, including a number of solar and lunar eclipses. Other histories, both local and national, contain astronomical observations. Beijing Observatory (1988) have made a search through both these sources and the dynastic histories; however, they do not always give the full record of an observation. Accordingly, this work has only been used as a secondary source in searching for observations not included in the dynastic histories or the *Wen-hsien T'ung-k'ao*.

It should be noted that although the original manuscripts of the works mentioned above have nearly all long since been lost, late copies are still in print today. However, this may have led to scribal errors, both ancient and modern, being introduced into the texts.

6.4 Calendrical Astronomy in China

The Chinese character *Li* is usually translated as "calendar" or "astronomical system", but is perhaps best thought of as including both of these meanings. A *Li* was a complete system for calculating the motion of the heavenly bodies and as a direct result this produced the reckoning of days, months and years which we term a calendar. As "calendar" has become the most widely used translation of *Li*, I shall adopt it with the proviso that it is remembered that it also applies to the other aspects of astronomical computation that are part of a *Li*.

As noted above, the Emperor received his mandate to govern from Heaven. In return he was expected to supervise the heavenly rituals, for only he could perform this service on behalf of his subjects (Yabuuti 1973). Heavenly phenomena fell into two classes; those that could be predicted, and those that could not. Regular, predictable events held no astrological importance, but unexpected events, such as a comet or an unpredicted eclipse, indicated that Heaven was displeased with the Emperor's rule. Therefore, the calendar was seen as a way of regulating the sky and so reducing the number of ominous events. If a calendar was failing to predict events such as eclipses, this would provide a motive for reforming the calendar. Furthermore, at times of political upheaval, such as at the start of a new dynasty, it was necessary for the Emperor to reform the calendar to establish his right to govern:

> "When a new dynasty rose by accepting the Heavenly Ordinance, at first it had to be prudent. It had to obey the will of Heaven by renewing the basis of all things: the calendar and the colour ... In founding a new dynasty, the Emperor should not depend upon former institutions."
>
> [*Shih-chi*; trans. Yabuuti (1974)]

Thus, this principle of "Reformation by the Heavenly Ordinance", whereby a new dynasty received its mandate to govern from Heaven, was responsible for many of the early reformations of the calendar (Yabuuti 1974). Furthermore, at least in the early period of Chinese history, even when a calendar was failing to make adequate predictions, reformation could only occur when there was the political will to do so (Cullen 1993).

In all there were more than fifty calendars officially adopted in China from the Han to the Ch'ing dynasties. These are listed in Table 6.3, which is based on the work of Yabuuti (1963a, 1963b).[2] It is worth stressing, however, that only in a small number of cases was there any significant difference between a new calendar and those that had gone before. In addition to the fifty or so calendars that were officially adopted by the Chinese state, nearly as many again were compiled but not accepted. Once more, the majority of these calendars varied little from its predecessors. However in a small number of cases, such as the *Chiu-chih-li* which was based on Indian astronomical methods (Yabuuti 1979), they were radically different from the traditional Chinese calendars.

[2] The gaps in the Table relate to dates where it is not clear which calendar was adopted.

Calendar	Compiler	Date of Use
Ssu-fen-li	Unknown	c. 400–104 BC
Ts'ang-t'ung-li	Liu Hsin	104 BC– AD 84
Ssu-fen-li	Li Fan	AD 85–263
Ch'ien-hsiang-li	Liu Hung	AD 222–280
Ching-ch'u-li	Yang Wei	AD 237–451
San-chi Chia-tzu-li	Chiang Chi	AD 384–417
Hsuan-shih-li	Chao Fei	AD 412–439 & AD 452–522
Yuan-chia-li	Ho Ch'eng-tien	AD 445–509
Ta-ming-li	Tsu Chung-chih	AD 510–589
Cheng-kuang-li	Chang Lung-hsiang	AD 523–565
Hsing-ho-li	Li Yeh-hsing	AD 540–550
T'ien-pao-li	Sung Ching-yeh	AD 551–557
Chou-li	Ming K'o-jang	c. AD 559
T'ien-ho-li	Chen Luan	AD 566–578
Tah-hsiang-li	Ma Hsien	AD 579–583
K'ai-huang-li	Chang Pin	AD 584–596
Ta-yen-li	Chan Chou-hsuan	AD 597–617
Mao-yin-li	Fu Jen-chun	AD 619–665
Lin-te-li	Li Ch'ung-feng	AD 665–728
Ta-yen-li	I Hsing	AD 729–762
Chih-te-li	Han Ying	AD 758–763
Wu-chi-li	Kuo Hsien-chih	AD 763–783
Cheng-yuang-li	Hsu Ch'eng-ssu	AD 783–806
Kuang-hsiang-li	Hsu Ang	AD 807–821
Hsuan-ming-li	Hsu Ang	AD 822–892
Ch'ung-hsuan-li	Pien Kang	AD 893–907
T'iao-yuan-li	Ma Ch'ung-chi	AD 939–944 & AD 947–994
Ch'in-t'ien-li	Wang P'o	AD 958–963
Ying-t'ien-li	Wang Ch'uno	AD 964–982
Ch'ien-yuan-li	Wu Chao-su	AD 983–1000
Ta-ming-li	Ku Chun	AD 995–1136
I-t'ien-li	Shih Hsu	AD 1001–1023
Ch'ung-t'ien-li	Ch'u Yen & Sung Ts'ung	AD 1024–1064 & AD 1068–1074
Ming-t'ien-li	Chou Ts'ung	AD 1065–1067
Feng-yuan-li	Wei P'o	AD 1075–1093
Kuan-t'ien-li	Huang Chu-ch'ing	AD 1094–1102
Chan-t'ien-li	Yao Shunpu	AD 1103–1105
Chi-yuan-li	Yao Shung-pu	AD 1106–1130 & AD 1168
Ta-ming-li	Yang Chi	AD 1137–1181
T'ung-yuan-li	Chen Tei	AD 1136–1167
Ch'ien-tao-li	Liu Hsaio-jung	AD 1168–1176
Ch'ung-hsi-li	Liu Hsiao-jung	AD 1177–1190
Revised Ta-ming-li	Chao Chih-wei	AD 1182–1280
Hui-yuan-li	Liu Hsiao-jung	AD 1191–1198
T'ung-t'ien-li	Yang Chung-pu	AD 1199–1207
K'ai-hsi-li	Pao Huan-chih	AD 1208–1251
Ch'un-yu-li	Li Tech'ing	AD 1252
Hui-t'ien-li	T'an Yui	AD 1253–1270
Ch'eng-t'ien-li	Ch'en Ting	AD 1271–1276
Pen-t'ien-li	Teng Kuan-chien	AD 1277
Shou-shih-li	Kuo Shou-ching	AD 1280–1368
Ta-t'ung-li	Yuan Tung	AD 1368–1661
Shih-hsien-li	Jesuits	AD 1665–1912

Table 6.3: Officially adopted Chinese calendars.

Number	Name	Aproximate Gregorian Date	Remarks
1	*Tung-chih*	22 December	Winter Solstice
2	*Hsiao-han*	6 January	
3	*Ta-han*	20 January	
4	*Li-ch'un*	4 February	
5	*Yu-shui*	19 February	
6	*ch'ing-che*	6 March	
7	*Ch'un-fen*	21 March	Vernal Equinox
8	*Ch'ing-ming*	5 April	
9	*Ku-yu*	21 April	
10	*Li-hsia*	6 May	
11	*Hsiao-man*	22 May	
12	*Mang-chung*	6 June	
13	*Hsia-chih*	22 June	Summer Solstice
14	*Hsiao-shu*	8 July	
15	*Ta-shu*	23 July	
16	*Li-ch'iu*	8 August	
17	*Ch'u-shu*	24 August	
18	*Po-lu*	8 September	
19	*Ch'iu-fen*	23 September	Autumnal Equinox
20	*Han-lu*	9 October	
21	*Shuang-hsiang*	24 October	
22	*Li-tung*	8 November	
23	*Hsiao-hsueh*	23 November	
24	*Ta-hsueh*	8 December	

Table 6.4: The 24 *Chieh-ch'i* (Based on Yabuuti (1963a)).

The primary use of the Chinese calendar was to produce a reckoning of days, months and years. We may think of this as being a calendar in the same sense as our Gregorian calendar, although, of course, its operational rules are completely different. Most importantly, the Chinese calendar is a luni-solar calendar, that is, it is based on the movement of both the Moon and the Sun. The first day of a month is defined as the day on which the Sun and the Moon are in conjunction. Thus, there are either 29 or 30 days in each month, where a day is defined as lasting from one midnight to the next. However, a solar year of about 365.24 days is not equal to an integer number of months; there is an excess of about 11 days over twelve months. In order to reconcile the months and the years, it is necessary to make every every second or third year a leap year containing an intercalary month. Initially, this month was added whenever it was judged necessary on an *ad hoc* basis, but by at least the fourth century BC, a 19 year cycle, identical to the Metonic Cycle of Ancient Greece, was used (Yabuuti 1963a).

Using the 19 year cycle, it was possible to determine which years should be leap years. The next problem was to decide at what time of the year the intercalary month should be inserted. The basic method for solving this problem was given in the *Ssu-fen-li*. A solar year was divided into 24 equal parts starting from the winter solstice, each part lasting slightly more than fifteen days. These are called the 24 *Chieh-ch'i*, and are listed in Table 6.4. Twelve of these *Chieh-ch'i*, every other one starting with the winter solstice (i.e., the odd numbered *Chieh-ch'i* in Table 6.4), are called *Chung-ch'i*. Since the gap between two *Chung-ch'i* is slightly more than 30 days, occasionally a month will go by that does not contain one of them. Such months then became intercalary.

The method of using the *Chieh-ch'i* to determine intercalary months remained basically unaltered up until the *Shih-hsien-li*, used during the Ch'ing dynasty, was replaced by the Gregorian calendar in AD 1912. Generally, only the accepted value for the length of the solar year and the synodic month changed from calendar to calendar. However, during the T'ang dynasty, the start of a month changed from being determined by the moment of mean conjunction to the moment of true conjunction (Yabuuti 1963a). Furthermore, in the *Shih-hsien-li*, the *Chieh-ch'i*, which had been determined by the length of the solar year, came to be defined as the time for the Sun to move through 30° (Liu

	tzu	*ch'ou*	*yin*	*mao*	*ch'en*	*ssu*	*wu*	*wei*	*shen*	*yu*	*hsu*	*hai*
chia	1		51		41		31		21		11	
i		2		52		42		32		22		12
ping	13		3		53		43		33		22	
ting		14		4		54		44		34		24
wu	25		15		5		55		45		35	
chi		26		16		6		56		46		36
keng	37		27		17		7		57		47	
hsin		38		28		18		8		58		48
jen	49		39		29		19		9		59	
kuei		50		40		30		20		10		60

Table 6.5: The sexagenary cycle.

& Stephenson 1998).

Years in the Chinese calendar were given in reign periods. These are similar to the regnal years used, for example, in Babylon, but differ in that they need not necessarily start with the accession year of an emperor. Sometimes an emperor might proclaim a new reign period three, four or occasionally even more times during his life. Generally, this would be prompted by the occurrence of an unusually auspicious event. In addition to the reign periods, a continuous count of years in a 60 year cycle was also used. Similarly, a 60 day count of days has been in continuous use, seemingly from as early as the Shang period down to the present day. This known as the sexagenary cycle. Days and years in this cycle are given by a combination of one of the ten *t'ien-kan* or "celestial stems" with one of the twelve *ti-chih* or "earthly branches." For example, the first day or year of a cycle is *chia-tzu*, the second *i-ch'ou*, and so on. The full sexagenary cycle is shown in Table 6.5. The celestial stems and the earthly branches are also used in other parts of Chinese life. For example, the celestial stems label each of the twelve double-hours by which time was measured, while both the stems and branches are used as direction indicators.

As dates in the Chinese calendar are generally defined both by the year, month, and day, and by the day on the sexagenary cycle, it is usually possible to accurately convert the date to the Julian calendar. For this purpose the tables of Hsueh & Ou-yang (1956) and Wong (1902) have been used. In virtually all cases, the dates of all the eclipses investigated in this work agreed exactly with those of computed eclipses when converted to the Julian calendar. The exceptions may be explained as minor scribal errors in the published text.

Besides providing a method for reckoning the passage of days, the next most important use for the Chinese calendar was to predict the occurrence of eclipses. As Li Ch'ien wrote in thirteenth century:

> "The exactitude of an astronomical system stands and falls on its treatment of eclipses. In this computational art exactitude is hard to come by. There is always uncertainty about whether the (predicted) time is early or late, and whether the (forecast) immersion is too shallow or too deep. If exact agreement (with the phenomena) be the goal, there can be no room for chance."
>
> [*Yuan-shih*, 53; trans. Sivin (1997)]

These words not only reflect the importance of eclipse prediction in China, but also an awareness of the inherent difficulties in such a task. Indeed, it may have been the failure of the calendars to be able to accurately predict the circumstances of eclipses that led to early ideas that the physical world is too complex to be fully predictable (Sivin 1986). As early as AD 175 Ts'ai Yung was to write:

> "The astronomical regularities are demanding in their subtlety, and we are too far removed from the Sages [who founded this art]. Success and failure take their turns, and no technique can be correct forever."
>
> [*Hou-han-shu*, 2; trans. Sivin (1986)]

The earliest methods of eclipse prediction used in China were based upon numerical cycles deduced from past records of eclipse observations; in particular a cycle of 135 synodic months (Sivin 1969). This cycle is fairly successful for lunar eclipses, but cycles cannot be used to predict solar obscurations with any degree of accuracy. Accordingly, early calendars dealt almost exclusively with lunar eclipses. As the astrological importance of an event was negated if it was predicted beforehand, most early Chinese calendars erred on the side of caution by predicting too many rather than too few eclipses. If a predicted eclipse failed to appear, then it was supposedly because the emperor was sufficiently virtuous to have prevented it. Examples of the court officials congratulating the emperor in such cases are well documented in T'ang sources (Yabuuti 1973).

The first mathematical treatment of eclipse calculation without reference to an eclipse cycle is found in the *Ch'ing-ch'u-li*. In this third century AD calendar, solar and lunar eclipses were predicted to occur when the Sun was within about 15° of the node of the lunar orbit. It allowed the magnitude and duration of the eclipse to be calculated, and even gave a rough description of the entrance angle of the shadow (Yabuuti 1963a). As with all of the early calendars, the *Ch'ing-ch'u-li* probably took the site of the Imperial Observatory at Yang-cheng (latitude 34.43°, longitude -113.03°), near Lo-yang, as its meridian. It was not until the eighth century AD that attempts were made to try and correct the calendar for different locations. This was in the *Ta-yen-li* compiled by the Buddhist monk I Hsing. In AD 725, I Hsing organized for the length of the shadow from a gnomon at the solstice and equinox to be measured at a number of stations on a roughly north-south line through China.[3] Using these measurements he was able to make crude adjustments to his calculations to take account of differences in latitude. However, as the generally accepted cosmology of China at this period was based on a flat Earth, there was no concept of longitude, and so no corrections could be applied to take account of east-west location in the eclipse calculations.

In addition to introducing a correction for location into his calendar, I Hsing also took into account the inequalities in the motion of the Sun and the Moon, and, for solar eclipses, the effects of lunar parallax. Magnitudes were calculated on a scale of 1 to 15, and from these the duration of a lunar eclipse was obtained by adding 2 *k'o* if the magnitude was less than 5, 4 *k'o* if it was less than 10, and 5 *k'o* if it was greater than 10.[4] In the case of solar eclipses, 2 *k'o* was simply added to the magnitude to give the duration. Similar methods were used in other calendars, although the magnitude was often given on a scale of 1 to 10 in later periods.

Following the *Ta-yen-li*, the *Hsuan-ming-li* showed further improvement by taking into account the effects of parallax more precisely. Many more calendars were adopted over the next four centuries, but it was not until Kuo Shou-ching produced the *Shou-shih-li* in AD 1280 that a further significant advancement was made. So successful was the *Shou-shih-li* that it was used from its adoption in AD 1280 until the end of the Ming dynasty with only one minor modification when it became the *Ta-t'ung-li* in AD 1368. Sivin (1997) has translated the *Shou-shih-li I*, a discussion of the calendar contained in the *Yuan-shih*, into English in an unpublished manuscript. A detailed discussion of the *Shou-shih-li* is given by Nakayama (1969: 123–150). Unlike most earlier calendars, the *Shou-shih-li* was able to calculate not only the time of conjunction and the duration of an eclipse, but all of the phases of lunar and solar eclipses.

It was not until the coming of the Jesuits missionaries in the seventeenth century that further significant improvements in the techniques of eclipse prediction were made. The Jesuits employed European methods to obtain more accurate predictions than the official Chinese astronomers. They used this skill to obtain influence in the Chinese court in the hope of converting the Chinese to Christianity from the top down.

[3]See *Chiu T'ang-shu*, 35 for a description of the work. This has been translated and discussed by Beer et al. (1961), who remark that it is "one of the most remarkable pieces of organized field research in the early middle ages."

[4]The *k'o* is a unit of time such that there are 100 *k'o* in one day. See Section 6.5 below.

6.5 Units of Time

From the middle of the first millennium BC, three units of time were used simultaneously in China. These were the *shih* or "double hour", the *keng* or "night watch", and the *k'o* or "mark". The day was divided into twelve equal double hours named after the twelve earthly branches. The first double hour, called *tzu*, was centred on midnight (i.e., running from 11 p.m. to 1 a.m.) and was followed by the other earthly branches in order. Sometimes the double hour would be split into two halves: the *ch'u* or "initial" half and the *cheng* or "central" half. Thus the first double hour contained an initial half lasting from 11 p.m. to midnight and a central half lasting from midnight to 1 a.m.

The night watch was a seasonal unit of time defined as lasting for one fifth of the length of the night. Strangely, there is no similar seasonal time unit for use during the day. For the purposes of calculating the watches, the night was defined as lasting from dusk, or the end of evening twilight, to dawn, the start of morning twilight. Twilight was defined as lasting for a set amount of time throughout China with no concession to the fact that the observable length of twilight varies with the observer's latitude. Initially the length of twilight was set as 3 marks (0.72 hours); however, after the start of the Later Han dynasty (AD 25), a length of $2\frac{1}{2}$ marks (0.60) hours was adopted. At the latitude of central China, therefore, the night watch varied in length from about 2.6 hours in winter to about 1.6 hours in summer. Each night watch was further subdivided into five equal parts, known before the Sui dynasty as *ch'ang* or "calls". during the Sui as *ch'ou* or "rods", and later as *tien* or "points".

Finally, the day was usually divided into 100 intervals called marks. This meant that there were $8\frac{1}{3}$ marks in a double hour,[5] making it difficult to use the two systems together. To simplify matters, on the advice of Hsia Ho-ling, in 5 BC the emperor Ai decreed that there would be 120 marks in a day, and hence 10 marks in each double hour. However, after only a few months he reversed this decision:

> "In the eighth month, an imperial edict said, 'The Expectant Appointee Hsia Ho-ling and others gave advice that (We) should change the year-period, alter (Our) title, and increase the (number of) graduations on the clepsydra, whereby (We) could (secure) permanent place for the clan (ruling) the state. We mistakenly listened to the advice of (Hsia) Ho-liang and the others, hoping to obtain blessings for (all) within the (four) seas. (But) in the end there was no happy verification (of their promises); they have all gone contrary to the Classics, turned their backs on ancient (practices), and are not in accordance with the needs of the times. The decree of the sixth month and (the day) *chia-tzu*, except for the order of an amnesty, is all expunged. (Hsia) Ho-liang and the others have gone contrary to the (right) Way and misled the crowd; they are to be committed (to the charge of) the high officials.' They all suffered death for their crimes."
>
> [*Han-shu*, 11; trans. Dubs (1955: 31–32)]

Not for the last time would politics impede scientific progress in China. Indeed, although the experimental increase to 120 marks was repeated by Wang Mang when he overthrew the Han dynasty in AD 9, it was once again rejected upon the restoration of Han power, and it was to be another five centuries before changes in the number of marks in a day were proposed again. This was at the order of the emperor Wu of Liang in AD 507. He decreed that there would be 96 marks in a day, making 8 marks in a double hour. In AD 554 the number was increased to 108; however, neither of these numbers proved popular and so in AD 560 the Ch'en emperor Wen returned to the classical definition of 100 marks in a day (Maspero 1939). This remained unaltered until AD 1628, when, on the recommendation of Jesuit astronomers, the last Ming emperor T'ai-tsung adopted emperor Wu's system of 96 marks in the day. This was used until modern times.

As one mark lasts for $\frac{1}{100}$th of a day (14.4 minutes), it was necessary to split the mark into smaller divisions named *fen*. The number of *fen* in a mark varied from dynasty to dynasty, and indeed from calendar to calendar within a dynasty. At some times it could be as few as 24 *fen* in a mark, at others as many as 150 *fen* in a mark.

[5] Or, alternatively, $4\frac{1}{6}$ marks in each of the initial and central halves of a double hour if this system was being used.

As I have noted, at most periods of Chinese history there were $8\frac{1}{3}$ marks in each double hour. Thus each double hour contained eight standard marks, plus a period that was only one-third of the length of a standard mark. This short period was called the *hsiao-k'o* or "small mark". Stephenson (1997b), Cohen & Newton (1983), and others have assumed that the small mark was always at the end of each double hour. However, none of these authors give a justification for this assumption. For the period of the Sui dynasty at least, the situation is explained in chapter 19 of the *Sui-shu*. Here it is written that a single mark was split over three double hours, each double hour ending with a third of this mark (i.e., 20 *fen* as there were 60 *fen* in one mark at this period). For the first of the three double hours, the final small mark contained 20 *fen*, numbered 1 to 20. The second of the three double hours ended with twenty *fen* numbered 21 to 40, whilst the third double hour concluded with twenty *fen* numbered 41 to 60 (Maspero 1939). This system was repeated every three double hours with the result that the small mark was always at the end of the double hour.

Maspero (1939) discusses the *Lou-k'o ching* or *Book of the Clepsydra*, written in AD 938 during the Wu-tai period. This work explains that at this period the double hours were split into two halves each containing 4 marks followed by 10 *fen*. Once more there were 60 *fen* in each double hour at this time. These are only isolated cases, however, and I am not aware of any other similar written evidence for the rest of Chinese history. Fortunately, it is possible to use some of the astronomical data contained in the dynastic histories to provide information for the other periods.

Contained within the calendar treatise of a number of the dynastic histories are details of the time of sunrise and sunset for the 24 *Chieh-ch'i* throughout the year.[6] These are the canonical values for Yang-cheng which were accepted for use in the various calendars, given in terms of double hours, marks and *fen*. Sunrise and sunset times are given in chapter 17 of the *Sui-shu*, chapter 32 of the *Chiu T'ang-shu*, and chapters 70 and 76 of the *Sung-shi*. Maspero (1939) has translated and discussed the sunrise and sunset timings from the *Sui-shu*, together with values from the Wei dynasty whose source is unknown to me.[7] In all cases, as the values given in the calendar treatise are for the 24 *Chieh-ch'i*, they are symmetrical about the solstices. Therefore, only values for the first 13 *Chieh-ch'i* will be considered.

Table 6.6 shows the times of sunrise and sunset recorded in the Wei dynasty, together with the times given by modern computation. In the table, the original times have been converted from double hours, marks and *fen* assuming that the small mark was at the end of the double hour. Figure 6.1 shows the difference between the recorded and the computed times of sunrise and sunset from the Wei dynasty. Clearly there is no evidence for any systematic error in the recorded times. Alternatively, if the small mark had been assumed to have been, say, at the beginning of the double hour, then a constant of +0.12 hours would have been added to all of the points on the graph, thus moving them significantly away from the zero error line. Therefore, the recorded sunrise and sunset times throughout the year have their best agreement with the computed values when we adopt the first assumption. This is sufficient evidence to prove that, during the Wei dynasty, the small mark was always at the end of each double hour.

Similarly, Tables 6.7 and 6.8 show the sunrise and sunset times for the Sui and T'ang dynasties respectively. Once more, it is initially assumed that the small mark is at the end of every hour. The errors in the times are shown in Figures 6.2 and 6.3. As with the Wei times, there is no evidence for any systematic error in the records when the small mark is assumed to be at the end of the hour. Thus we may safely assume that during these dynasties, this assumption is also correct.

Chapters 70 and 76 of the *Sung-shih* give the canonical times of sunrise and sunset for the *I-t'ien-li* and the *Ch'ung-t'ien-li* calendars respectively. Both sets of times are given in marks and *fen*

[6]In China, as in most of the world, sunrise and sunset were defined to be the moments when the upper limb of the Sun crossed the horizon (Needham 1959).

[7]It should be noted that Maspero analyses the sunrise and sunset timings to try to determine their reliability, having already assumed that the small mark was at the end of the double hour on the basis of the limited written evidence discussed above.

			Sunrise			Sunset	
Chieh-ch'i	Gregorian Date	Rec. (h)	Comp. (h)	Comp. - Rec. (h)	Rec. (h)	Comp. (h)	Comp. - Rec. (h)
1	22 December	7.18	7.07	-0.11	16.82	16.93	+0.11
2	6 January	7.08	7.02	-0.06	16.90	16.98	+0.08
3	20 January	6.97	6.89	-0.10	17.02	17.11	+0.09
4	4 February	6.75	6.69	-0.06	17.23	17.31	+0.08
5	19 February	6.48	6.45	-0.03	17.50	17.55	+0.05
6	6 March	6.18	6.19	+0.01	17.80	17.81	+0.01
7	21 March	5.88	5.92	+0.04	18.10	18.08	-0.02
8	5 April	5.58	5.66	+0.08	18.40	18.35	-0.05
9	21 April	5.30	5.38	+0.08	18.65	18.62	-0.03
10	6 May	5.08	5.15	+0.07	18.90	18.86	-0.04
11	22 May	4.93	4.94	+0.01	19.07	19.06	-0.01
12	6 June	4.80	4.81	+0.01	19.18	19.19	+0.01
13	22 June	4.78	4.77	-0.01	19.22	19.23	+0.01

Table 6.6: Sunrise and sunset times from the Wei dynasty.

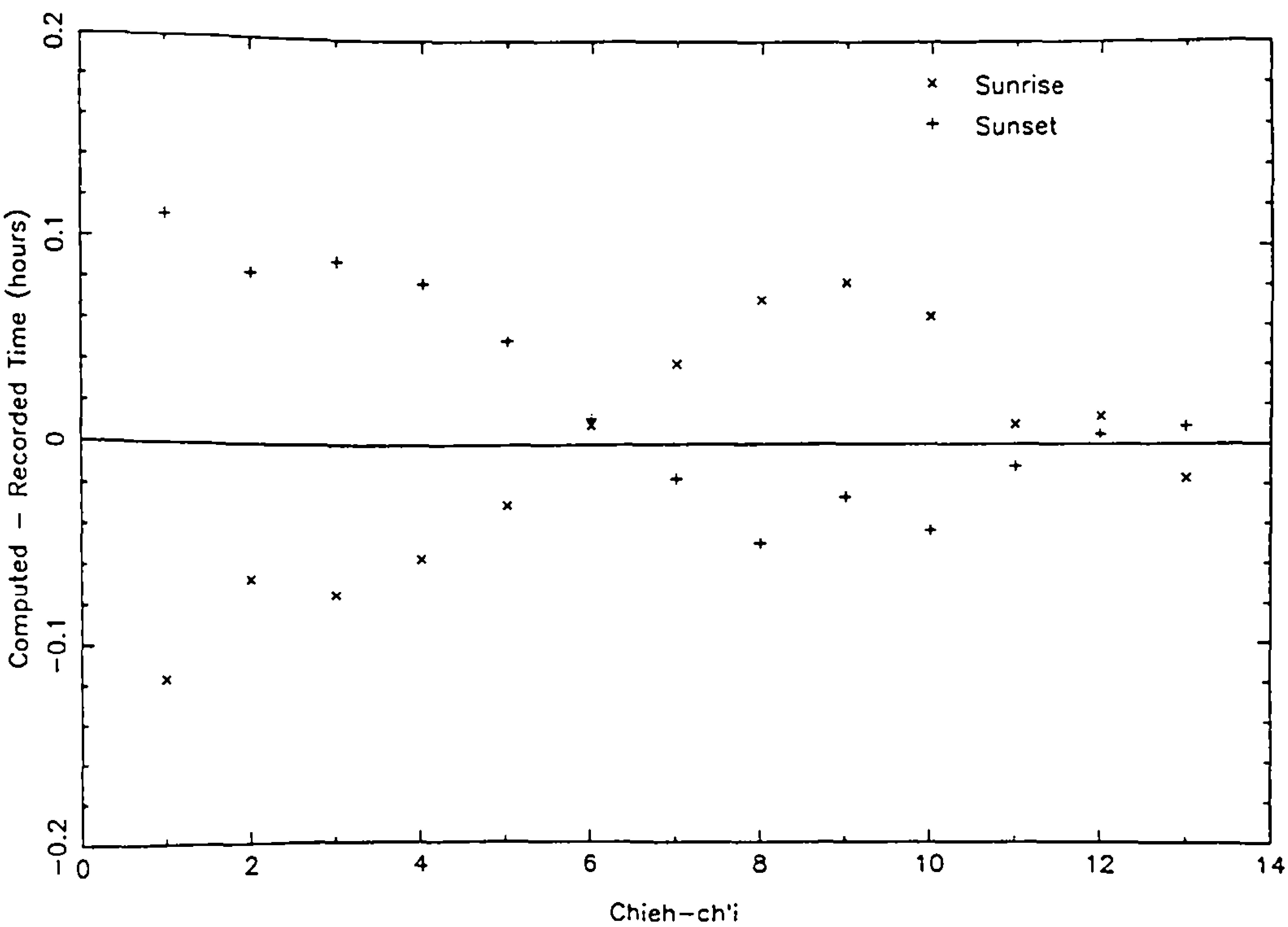


Figure 6.1: The error in the times of sunrise and sunset recorded during the Wei dynasty.

		Sunrise			Sunset		
Chieh-ch'i	Gregorian Date	Rec. (h)	Comp. (h)	Comp. - Rec. (h)	Rec. (h)	Comp. (h)	Comp. - Rec. (h)
1	22 December	7.20	7.07	-0.13	16.84	16.93	+0.09
2	6 January	7.13	7.02	-0.11	16.87	16.98	+0.11
3	20 January	6.96	6.89	-0.07	17.00	17.11	+0.11
4	4 February	6.80	6.69	-0.11	17.21	17.31	+0.10
5	19 February	6.54	6.45	-0.09	17.44	17.55	+0.11
6	6 March	6.25	6.19	-0.06	17.75	17.81	+0.06
7	21 March	5.94	5.92	-0.02	18.02	18.08	+0.06
8	5 April	5.67	5.66	-0.01	18.37	18.35	-0.02
9	21 April	5.35	5.38	+0.03	18.64	18.62	-0.02
10	6 May	5.11	5.15	+0.04	18.89	18.86	-0.03
11	22 May	4.93	4.94	+0.01	19.07	19.06	-0.01
12	6 June	4.82	4.81	-0.01	19.18	19.19	+0.01
13	22 June	4.84	4.77	-0.06	19.20	19.23	+0.03

Table 6.7: Sunrise and sunset times recorded in chapter 17 of the *Sui-shu*.

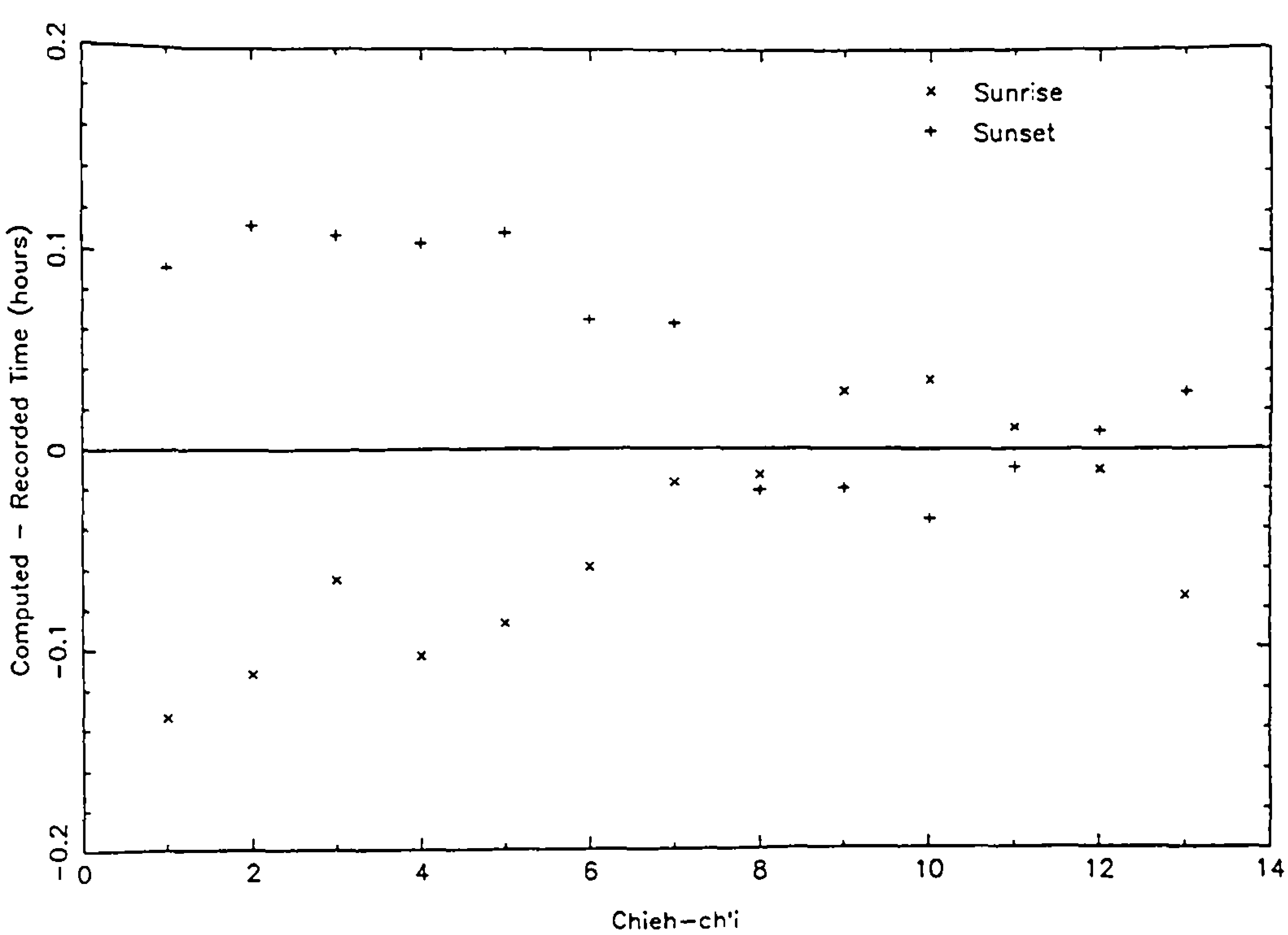


Figure 6.2: The error in the times of sunrise and sunset recorded in chapter 17 of the *Sui-shu*.

Chieh-ch'i	Gregorian Date	Sunrise Rec. (h)	Sunrise Comp. (h)	Sunrise Comp. - Rec. (h)	Sunset Rec. (h)	Sunset Comp. (h)	Sunset Comp. - Rec. (h)
1	22 December	7.20	7.07	-0.13	16.80	16.93	+0.13
2	6 January	7.13	7.02	-0.11	16.83	16.98	+0.15
3	20 January	6.99	6.89	-0.10	17.01	17.11	+0.10
4	4 February	6.79	6.69	-0.10	17.21	17.31	+0.10
5	19 February	6.54	6.45	-0.09	17.46	17.55	+0.09
6	6 March	6.25	6.19	-0.06	17.75	17.81	+0.06
7	21 March	5.94	5.92	-0.02	18.06	18.08	+0.02
8	5 April	5.63	5.66	+0.03	18.37	18.35	-0.02
9	21 April	5.35	5.38	+0.03	18.65	18.62	-0.03
10	6 May	5.12	5.15	+0.03	18.88	18.86	-0.02
11	22 May	4.93	4.94	+0.01	18.99	19.06	+0.07
12	6 June	4.82	4.81	-0.01	19.18	19.19	+0.01
13	22 June	4.80	4.77	-0.03	19.20	19.23	+0.03

Table 6.8: Sunrise and sunset times recorded in chapter 32 of the *Chiu T'ang-shu*.

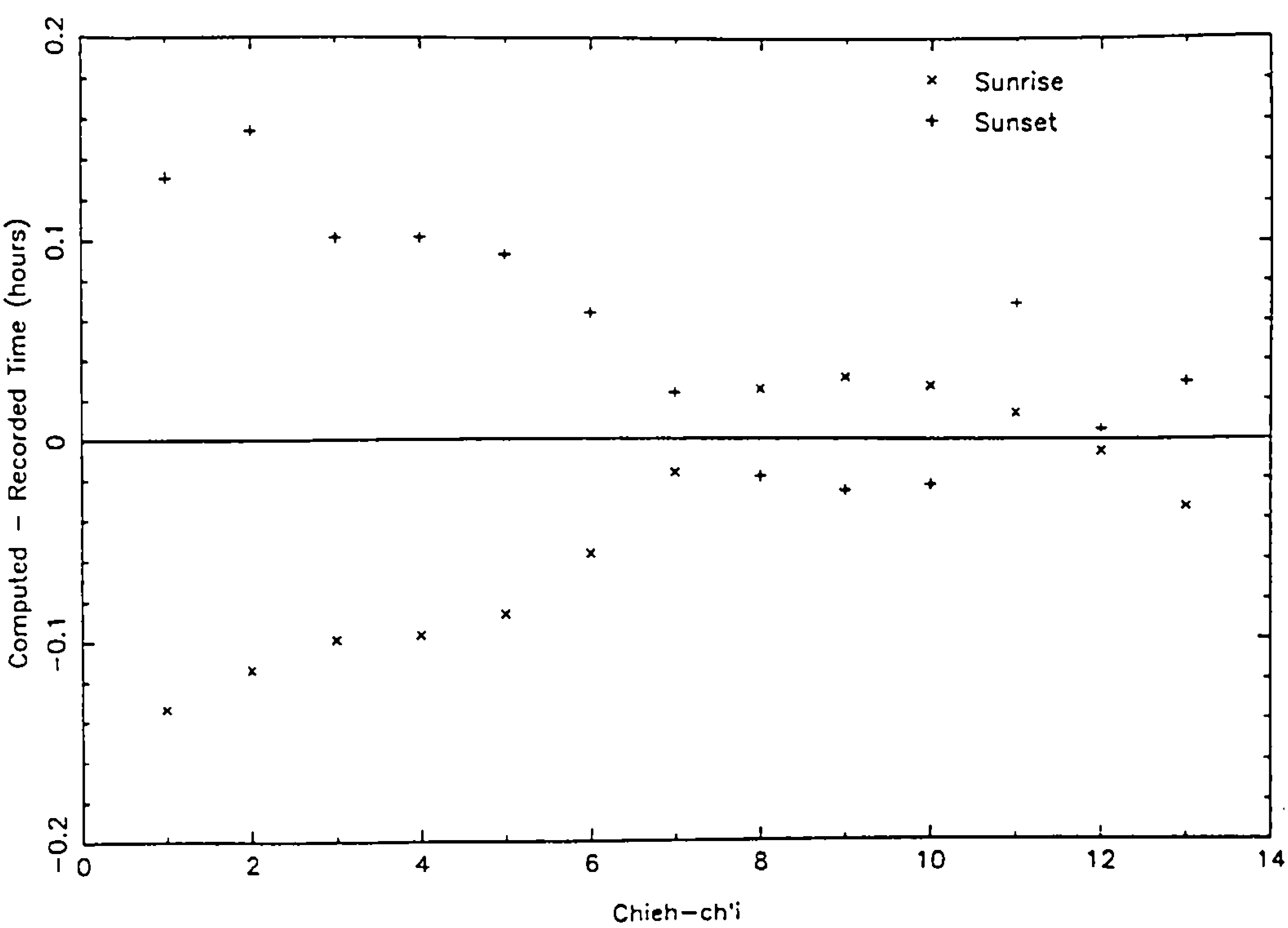


Figure 6.3: The error in the times of sunrise and sunset recorded in chapter 32 of the *Chiu T'ang-shu*.

		Sunrise			Sunset		
Chieh-ch'i	Gregorian Date	Rec. (h)	Comp. (h)	Comp. - Rec. (h)	Rec. (h)	Comp. (h)	Comp. - Rec. (h)
1	22 December	7.19	7.07	-0.12	16.80	16.93	+0.13
2	6 January	7.15	7.02	-0.13	16.84	16.98	+0.14
3	20 January	7.02	6.89	-0.13	16.98	17.11	+0.13
4	4 February	6.81	6.69	-0.11	17.18	17.31	+0.13
5	19 February	6.57	6.45	-0.12	17.42	17.55	+0.13
6	6 March	6.30	6.19	-0.11	17.69	17.81	+0.11
7	21 March	6.00	5.92	-0.08	18.00	18.08	+0.08
8	5 April	5.69	5.66	-0.03	18.30	18.35	+0.05
9	21 April	5.40	5.38	-0.02	18.59	18.62	+0.03
10	6 May	5.20	5.15	-0.05	18.84	18.86	+0.04
11	22 May	4.95	4.94	-0.01	19.04	19.06	+0.02
12	6 June	4.83	4.81	-0.02	19.16	19.19	+0.03
13	22 June	4.80	4.77	-0.03	19.19	19.23	+0.04

Table 6.9: Sunrise and sunset times given in chapter 70 of the *Sung-shih*.

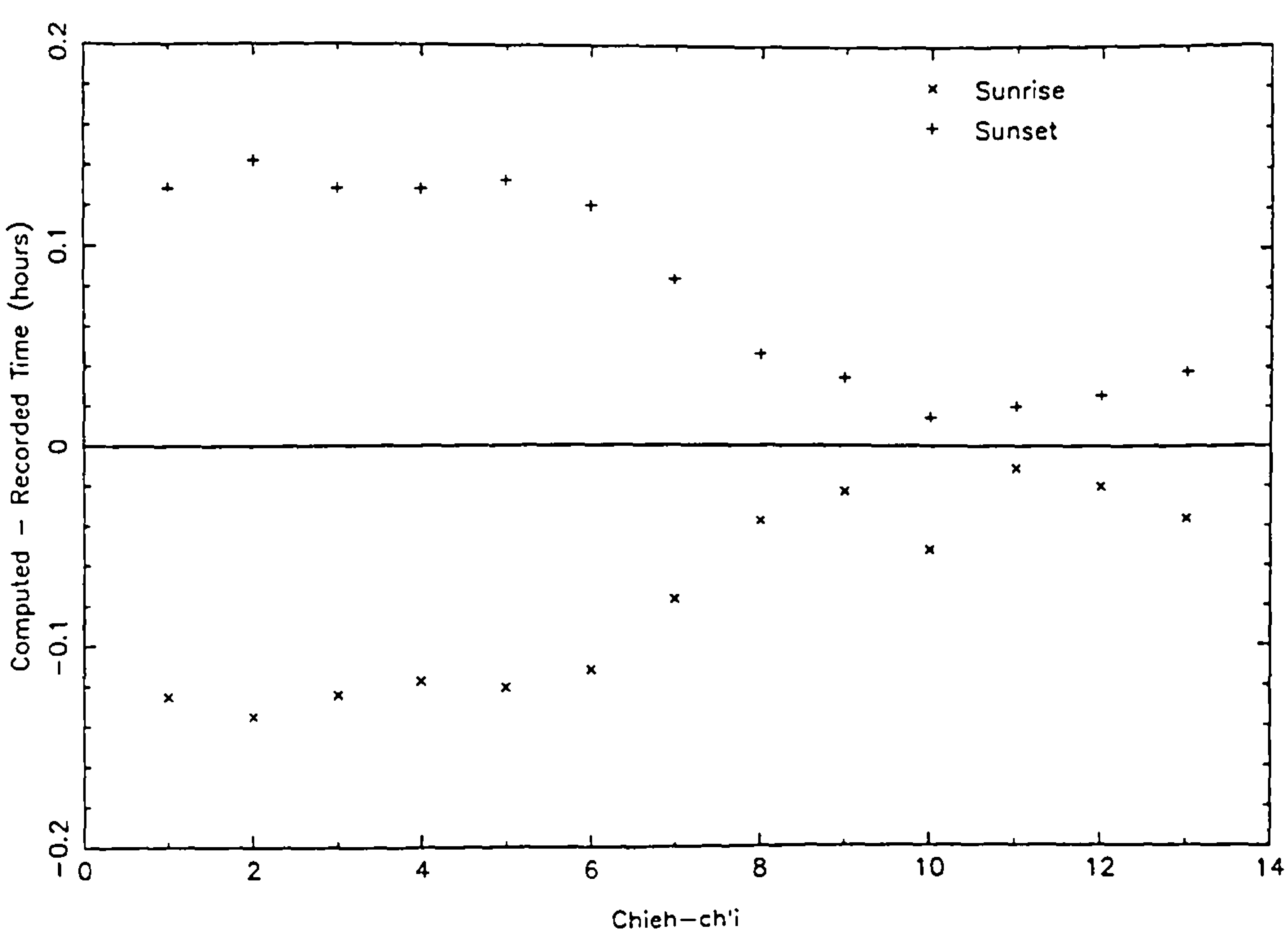


Figure 6.4: The error in the times of sunrise and sunset recorded in chapter 70 of the *Sung-shih*.

			Sunrise			Sunset	
Chieh-ch'i	Gregorian Date	Rec. (h)	Comp. (h)	Comp. - Rec. (h)	Rec. (h)	Comp. (h)	Comp. - Rec. (h)
1	22 December	7.20	7.07	-0.13	16.80	16.93	+0.13
2	6 January	7.16	7.02	-0.14	16.84	16.98	+0.14
3	20 January	7.04	6.89	-0.15	16.96	17.11	+0.15
4	4 February	6.81	6.69	-0.11	17.15	17.31	+0.16
5	19 February	6.60	6.45	-0.15	17.40	17.55	+0.15
6	6 March	6.31	6.19	-0.11	17.69	17.81	+0.11
7	21 March	6.00	5.92	-0.08	18.00	18.08	+0.08
8	5 April	5.69	5.66	-0.03	18.31	18.35	+0.04
9	21 April	5.40	5.38	-0.02	18.56	18.62	+0.06
10	6 May	5.15	5.15	+0.00	18.85	18.86	+0.01
11	22 May	4.96	4.94	-0.02	19.04	19.06	+0.02
12	6 June	4.84	4.81	-0.03	19.16	19.19	+0.03
13	22 June	4.80	4.77	-0.03	19.20	19.23	+0.03

Table 6.10: Sunrise and sunset times given in chapter 76 of the *Sung-shih*.

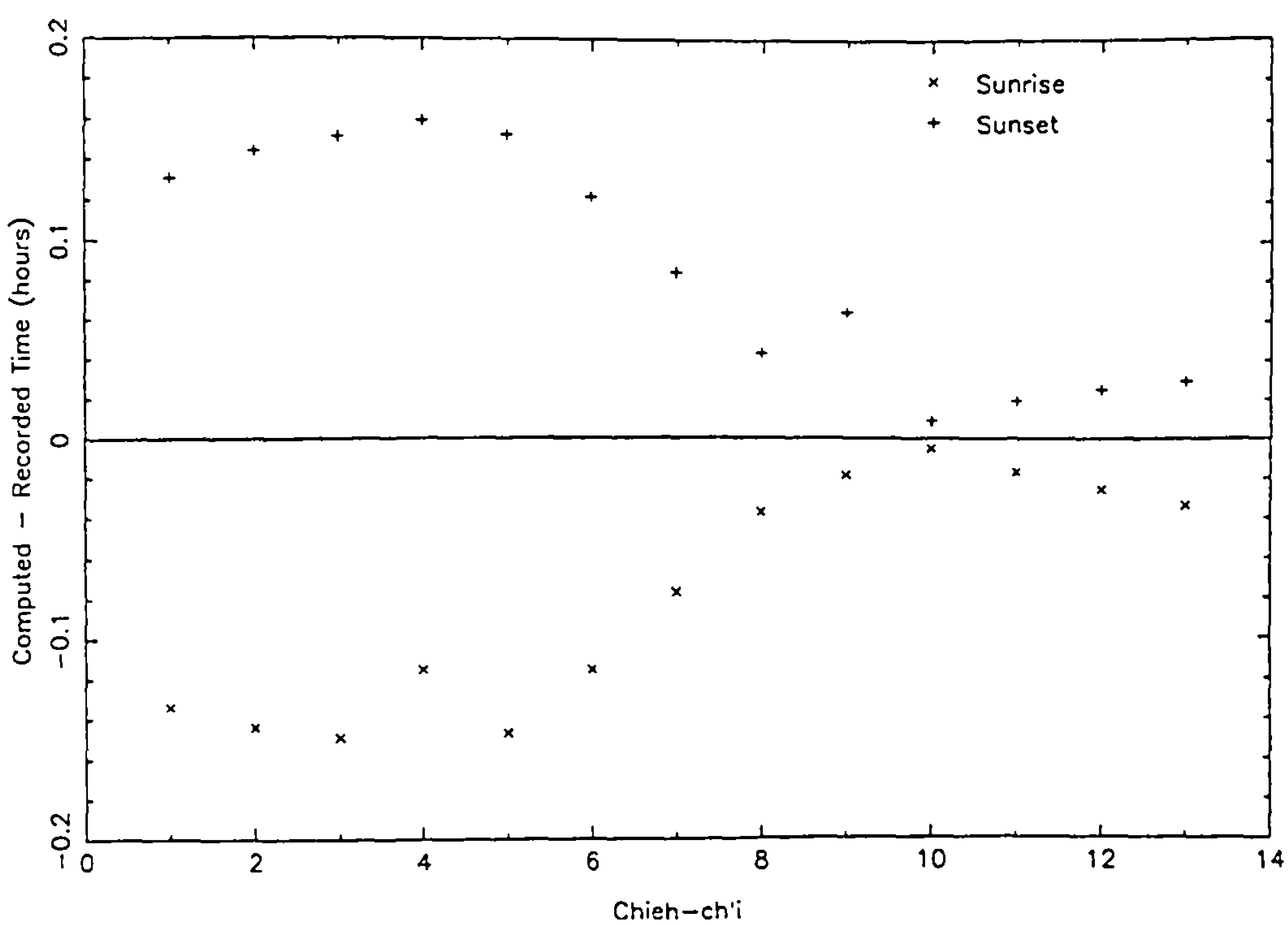


Figure 6.5: The error in the times of sunrise and sunset recorded in chapter 76 of the *Sung-shih*.

Shih	0 *k'o*	1 *k'o*	2 *k'o*	3 *k'o*	4 *k'o*	5 *k'o*	6 *k'o*	7 *k'o*	8 *k'o*
tzu	23.00	23.24	23.48	23.72	23.96	0.20	0.44	0.68	0.92
ch'ou	1.00	1.24	1.48	1.72	1.96	2.20	2.44	2.68	2.92
yin	3.00	3.24	3.48	3.72	3.96	4.20	4.44	4.68	4.92
mao	5.00	5.24	5.48	5.72	5.96	6.20	6.44	6.68	6.92
ch'en	7.00	7.24	7.48	7.72	7.96	8.20	8.44	8.68	8.92
ssu	9.00	9.24	9.48	9.72	9.96	10.20	10.44	10.68	10.92
wu	11.00	11.24	11.48	11.72	11.96	12.20	12.44	12.68	12.92
wei	13.00	13.24	13.48	13.72	13.96	14.20	14.44	14.68	14.92
shen	15.00	15.24	15.48	15.72	15.96	16.20	16.44	16.68	16.92
yu	17.00	17.24	17.48	17.72	17.96	18.20	18.44	18.68	18.92
hsu	19.00	19.24	19.48	19.72	19.96	20.20	20.44	20.68	20.92
hai	21.00	21.24	21.48	21.72	21.96	22.20	22.44	22.68	22.92

Table 6.11: The start of each mark of the double hours.

	chu (initial) half					*cheng* (central) half				
Shih	0 *k'o*	1 *k'o*	2 *k'o*	3 *k'o*	4 *k'o*	0 *k'o*	1 *k'o*	2 *k'o*	3 *k'o*	4 *k'o*
tzu	23.00	23.24	23.48	23.72	23.96	0.00	0.24	0.48	0.72	0.96
ch'ou	1.00	1.24	1.48	1.72	1.96	2.00	2.24	2.48	2.72	2.96
yin	3.00	3.24	3.48	3.72	3.96	4.00	4.24	4.48	4.72	4.96
mao	5.00	5.24	5.48	5.72	5.96	6.00	6.24	6.48	6.72	6.96
ch'en	7.00	7.24	7.48	7.72	7.96	8.00	8.24	8.48	8.72	8.96
ssu	9.00	9.24	9.48	9.72	9.96	10.00	10.24	10.48	10.72	10.96
wu	11.00	11.24	11.48	11.72	11.96	12.00	12.24	12.48	12.72	12.96
wei	13.00	13.24	13.48	13.72	13.96	14.00	14.24	14.48	14.72	14.96
shen	15.00	15.24	15.48	15.72	15.96	16.00	16.24	16.48	16.72	16.96
yu	17.00	17.24	17.48	17.72	17.96	18.00	18.24	18.48	18.72	18.96
hsu	19.00	19.24	19.48	19.72	19.96	20.00	20.24	20.48	20.72	20.96
hai	21.00	21.24	21.48	21.72	21.96	22.00	22.24	22.48	22.72	22.96

Table 6.12: The start of each mark of the single hours.

measured from the central half of a double hour.[8] The normal practice when using the two halves of the double hours was to measure up to $4\frac{1}{6}$ marks in each half separately. In these two cases, however, the full $8\frac{1}{3}$ marks were measured consecutively from the central half of the double hour. Thus the final 4 marks of the double hour were actually during the first half of the following double hour. To my knowledge, these are the only known examples of measuring the marks within a double hour from its midpoint rather than from its beginning.[9] Despite the unusual terminology used in the sunrise and sunset records from the *Sung-shih*, it is still possible to use them to test our assumption regarding the location of the small mark within the double hour. Tables 6.9 and 6.10 show the sunrise and sunset times from chapters 70 and 76 respectively. The errors in the times are shown in Figures 6.4 and 6.5. Once more, it is clear that there is no systematic error in the times, and so again it would seem that my assumption is justified.

Whilst there are no sunrise or sunset times recorded in the *Yuan-shih*, the values accepted in the *Shou-shih-li* have fortunately been preserved in the Korean *Chiljŏngsan Naepiŏn* calendar. This calendar from the Chosŏn dynasty was based upon the *Shou-shih-li* and its modified successor, the *Ta-t'ung-li*. Lee (1997) has analysed the sunrise times in this calendar and found them to be in good agreement with modern computation. This implies that the sunrise and sunset times from the *Shou-shih-li* and the *Ta-t'ung-li* are close to those given by modern computations. Consequently, during

[8]This is explicitly stated in the second set of times and may be inferred for the first set from the times themselves which would otherwise have sunrise and sunset an hour earlier than the true value.

[9]However, see the discussion of the anomalous eclipse timings recorded in the *Wen-hsien T'ung-k'ao* in Section 6.7.3 below.

the Yuan and Ming dynasties, the small mark must also have been the final mark in every double or half-double hour.

From the above tests at various periods of Chinese history, it is now possible to safely conclude that the small mark was always at the end of each double hour. By analogy, we may also assume that when the double hour was split into an initial and a central half, each containing $4\frac{1}{6}$ marks, the small mark (i.e., $\frac{1}{6}$ mark) was at the end of each half. Tables 6.11 and 6.12 show the divisions of each double and half double hour into the marks. The double hour commences with the "initial" mark (labelled "0 *k'o*" in the tables), followed by the first mark, and so on up to the eighth "small" mark.

It should be noted that the double hours and marks were time *intervals* rather than discrete moments (Needham et. al. 1986: 9). Thus, a time merely stated as being at a given mark within a given double hour could be at any moment between the beginning of that mark, as shown in Tables 6.11 and 6.12, and the beginning of the following mark. Therefore, unless the record specifically refers to the start or end of a given double hour or mark, the midpoint of the appropriate interval will be taken in the subsequent analysis.

6.6 Methods of Time Measurement

The clocks used by early Chinese astronomers were forms of clepsydra. These ranged from simple outflow devices to complicated mechanical clocks using water as the motive power source. The most primitive form of clepsydra used in China was the outflow water clock. This consisted of a container out of which water was allowed to flow and the passage of time was determined by the drop in the water level. However, by the first century BC, the inflow clepsydra was in general use (Needham 1959: 315–317). Instead of allowing the water to flow out of a container, the inflow clepsydra worked by collecting water in a container and using an indicator rod to determine the amount of water collected and thus the passage of time. A number of indicator rods would be used, each calibrated to give the time in double hours or in night watches.

The effect of temperature and humidity on the rate of flow of water in a clepsydra was known by at least the start of the Later Han dynasty. Needham (1959: 321–322) quotes a certain Huan T'an as saying that when he was Secretary at the Court it was his job to regulate the rate of flow of the clepsydras by comparing them with sundials. Maspero (1939) has asserted that the sundials could not be read with sufficient accuracy to be used for any other purpose than as regulators.

By the second century AD it was realised that if the water being collected was flowing from a container then the fall in the water level would reduce the water pressure and the rate of flow would slow down. Two principal methods were used to maintain a constant water level. The first method used one or more compensating tanks from which water would flow before eventually being collected at the lowest level. This had the effect of keeping the water level in the final outflow tank almost constant. In some clocks as many as six compensating tanks were used to achieve an almost uniform rate of water flow. The second method used to achieve a constant level of water was to place an overflow tank at the head of the series of compensating tanks. This had the effect of keeping all of the lower tanks at the same level so producing a highly uniform rate of flow.

By the 7th century AD devices called "steelyard clepsydras" were being used (Needham 1959: 327). These clepsydras measured time not by the use of an indicator rod but by weighing the water-receiving vessel. The length of time the clepsydra had been running would thus be proportional to the change in weight of the receiving vessel.

Development of the use of water to power a mechanical clock, which began towards the end of the 7th century AD (Forte 1988), culminated at the end of the 11th century with the building of a giant clock tower by Su Sung. The clock tower contained a water-power driven armillary sphere, an automatically rotated celestial globe and a number of bells and gongs to mark the times of the day in both double hours and marks and night watches. The clock was powered by water dripping from a clepsydra into rotating scoops. A translation of the *Hsin I Hsiang Fa Yuo*, Su Sung's description of the clock, together with a discussion of both the clock mechanism and the background to its development, is given by Needham, Wang & de Solla Price (1986).

A prototype of Su Sung's clock tower was built of wood in AD 1088 and was soon replaced by a permanent bronze construction in the Sung capital of Pien. Despite being threatened by a change of government in AD 1094, the clock tower remained in full working order until AD 1126 when the Chin Tartars captured Pien. The Chin took all of the captured astronomical instruments to their new capital Yen where they remained in use for some years before gradually wearing out. The last working part of the clock tower, the armillary sphere, continued in use until the Chin fled southwards from the Mongols in about AD 1215 leaving it behind in Yen (Needham 1965: 494–498).

On being driven out of their capital of Pien by the Chin Tartars in AD 1126, the Sung fled south. At their new capital of Lin-an, they soon set about trying to rebuild their lost astronomical instruments. Su Sung's son was asked to assist in the making of a clock to his father's designs, but his father's book containing a description of his clock was lost and family papers did not contain enough details to enable an identical one to be built. Many people investigated the water drive devices but none claimed to have been as successful as Su Sung. However, in AD 1172 Su Sung's book was recovered and printed in the south, once more allowing others to use his designs.

Interest in clock design continued throughout the following centuries with astronomers such as Kuo Shou-ching designing several clepsydras (Bo 1997). Indeed the last emperor of the Yuan was himself building clocks in the middle of the fourteenth century. However, during the Ming dynasty clock development had virtually ceased and by the time of the coming of the Jesuits in the seventeenth century the mechanical clock had disappeared and more basic clepsydras were again in use (Needham 1965: 508). The reason for this decline in clepsydra technology during the Ming was purely political. The first Ming emperor felt that the making of complicated mechanical clock was a dangerous activity, and when presented with a crystal clepsydra he immediately smashed it (Hua 1997). Subsequently, the emperor issued an Imperial Edict proclaiming that traditional clepsydras were to be used throughout the empire.

6.7 Timed Eclipse Records in Chinese History

Throughout Chinese history eclipses have been regarded as among the most astrologically significant of astronomical events. Solar eclipses in particular were seen as major portents, and, as such, are one of the most frequently reported types of heavenly observation from the *Ch'un-ch'iu* period onwards. Lunar eclipses held less value as omens, and it is not until the start of the fifth century AD that we begin to find systematic records of their observation.

Eclipse records are almost exclusively found in the dynastic histories, although, after the tenth century AD, a number of eclipse observations are also found in other works such as the *Wen-hsien T'ung-k'ao* and the *Sung-hui-yao Chi-k'ao*. Within the dynastic histories, most of the eclipse records are found in the annals, the astrological treatises, and the five-phases treatises. Many of the descriptions are very brief, noting no more than that on a certain day, "the Sun was eclipsed." However, if the eclipse was very large, then this would also often be noted, for the astrological importance of the eclipse was in direct relation to its magnitude, as is mentioned in the report of the eclipse on the 28th of April 360 AD:

> "A solar eclipse occurred on a *hsin-ch'ou* day, the first day of the eighth month in the 4th year of the *Sheng-P'ing* reign-period. It was almost a total eclipse observed (in the position of) *chio*. Whenever an eclipse covers a small portion of the Sun the calamity will be relatively small, but when it covers a large portion of the Sun the consequences will be much more serious."
>
> [*Chin-shu*, 12; trans. Ho (1966: 159)]

In this example, the eclipse occurred when the Sun was within *chio*, one of the 28 "lunar lodges" which correspond to zones of right ascension. Sometimes the position of the Sun would be given to the nearest degree[10] within a lunar lodge.[11] The astrological interpretation of an eclipse depended upon which lunar lodge the Sun was in, as is shown by the record of the eclipse on 22 June 103 AD in the five-phases treatise of the *Hou-han-shu*:

> "The Sun was eclipsed in the 22nd degree of *tung-ching*. *Tung-ching* is the mansion (lodge) in charge of wine and food, the duty of a wife: 'It will be theirs neither to do wrong nor to do good, only about the spirits and the food will they have to think.' In the winter of the previous year, the (Lady) Deng had become empress. She had the nature of a man, she participated in and had knowledge of affairs outside of the palace, therefore Heaven sent a symbol. During that year floods and rain damaged the crops."
>
> [*Hou-han-shu*, 27; trans. Beck (1990: 162)]

The above example illustrates two of the most important aspects of early Chinese eclipse records: astrological interpretation and political manipulation. This is particularly evident during the Former and Later Han dynasties, when many eclipse observations were interpreted in ways that were intended to criticise either the emperor or the government. Indeed, the level of political manipulation of the astronomical records in the dynastic histories of the Former and Later Han has led to serious questions being asked of their reliability as a genuine record of the observations being made at the time. As Dubs (1938, 1944, 1955), Eberhard (1957), and Bielenstein (1950, 1984) have noted, only a small proportion of the solar eclipses visible in China during the Former and Later Han dynasties are recorded in the *Han-shu* and the *Hou-han-shu*. Even allowing for the effects of adverse weather, the observational record is far from complete. Furthermore, Bielenstein (1950) found that there is significant evidence for a correlation between the amount of missing "observations" during an emperor's rule, and his popularity. Evidently, the record of observations, which it should be remembered is really a record of astrological interpretations, was being manipulated. Bielenstein (1950, 1984) is of the opinion that this was done by the officials of the time, whilst Eberhard (1957) prefers to think that while the officials may have played some part in the manipulation, it was mainly perpetrated by the compiler of the dynastic history himself.

In addition to the fact that the observational record in China is obviously far from complete, Foley (1989) has shown that at various periods in Chinese history, a number of the solar eclipses that were recorded could not in fact have been observed. Whilst in the later periods it would seem that many of these records were in fact unsuccessful attempts at predictions which failed either because the path of the eclipse passed completely to the north or to the south of China, or because the Sun was below the horizon at the time of the eclipse, many of the records during the Han dynasties occur on dates when the Sun was far away from one of the lunar nodes, and so do not appear to represent even crude attempts at prediction. Thus, they must have been inserted into the historical records for political purposes.

The eclipse records in the annals, astrological treatises and five-phases treatises very rarely give a precise measurement of the time of the observation. The only exceptions to this are two solar eclipses observed in AD 761 and AD 768. The observations of these eclipses are reported in chapter 36 of the *Chiu T'ang-shu*, as part of the astrological treatise.

In complete contrast to the general style of the eclipse records discussed above are a small number reported in the calendar treatises of the dynastic histories. These are given within discussions of the various systems used for predicting eclipses as examples of the reliability of the calendars. Generally, the descriptions of the eclipses given in the calendar treatises are very detailed, giving the time of the eclipse to the nearest mark or fifth of a night watch. Unlike the vast wealth of eclipse records from the astronomical treatises, only four of the dynastic histories, the *Sung-shu*, the *Sui-shu*, the *Sung-shih*, and the *Yuan-shih*, contain any eclipse records in their calendar treatise.

[10] Although it is customary to translate the character *Tu* as "degree" because it is a unit of angular measure, it should be noted that there are not 360 *Tu* in a circle. Instead, the *Tu* is defined such that there are the same number of *Tu* in a circle as there are days in a year. In other words, a circle contained about 365.25 *Tu*.

[11] See Stephenson (1994) for a list of the lunar lodges.

Before discussing the eclipse records in the calendar treatises and other sources in detail, it is necessary to note that very few eclipse records in Chinese history state a place of observation. However, we may assume that this was usually the appropriate capital of the time for the following reasons. Firstly, a small number of early eclipse observations note that the eclipse was *not* seen at the capital, but was instead reported from one of the provinces. This implies that the general practice *was* to observe from the capital, unless the observation was hindered by bad weather. Secondly, the Astronomical Bureau, which was based in the capital as it was necessary to be located near to the emperor so that it could report to him on short notice of any unusual observations that would act as portents, was the only place that had the instruments required to make the detailed observations reported in the calendar treatises. Finally, probably only observations made at the capital would as a rule be sufficiently important to include in an official history.

6.7.1 The *Sung-shu*, the *Sui-shu*, the *Chiu T'ang-shu*, and the *Sung-shih*

Chapter 12 of the *Sung-shu*, chapter 17 of the *Sui-shu*, chapter 36 of the *Chiu T'ang-shu* and chapter 82 of the *Sung-shih*, contain five, eleven, two, and five detailed records of eclipses respectively. Generally, these are compared with the details of the eclipses as predicted using the appropriate calendar of the time. I give below an example of a record from each of these sources. Full translations of all of these records are given in Appendix B.

- 26 October 440 AD

> "Yuan Chia reign period, 17th year, 9th month, 16th day, night of the full Moon. A lunar eclipse was calculated for the start of the hour *tzu*. The eclipse actually began at the end of the 15th day at the 1st call of the 2nd watch. At the 3rd call it was $\frac{12}{15}$ eclipsed. This was at $1\frac{1}{2}$ degrees in *mao*."
> [*Sung-shu*, 12]

- 1 August 585 AD

> "K'ai-Huang reign period, 5th year, 6th month, 30th day. According to the solar eclipse calendar (*T'ai-yang-kuei*) the sun should have been 6 degrees in *ch'i hsing*. At the calculated time of the start of the hour of *wu*, the Sun should have been $\frac{1}{15}$ eclipsed, the loss beginning from the south-west side. Now when observed, the Sun began to be eclipsed after the 6th mark of the hour *wu*. The loss came from the north-east side and the Sun was $\frac{6}{15}$ eclipsed. After the 1st mark of the hour *wei* it began to return. At the 5th mark it was returned to fullness."[12]
> [*Sui-shu*, 17]

- 5 August 761 AD

> "[Shang Yuan reign period], 2nd year, 7th month, *kuei-wei*. On the first day of the month the Sun was eclipsed. All of the great stars were visible. Ch'u T'an, the Head of the Astronomy Bureau, proclaimed to the Emperor that on (the day) *kuei-wei*, the Sun was dimmed. The loss began after the 6th mark of *ch'en*. After the 1st mark of *ssu* it was total. It was returned to fullness at the start of the 1st mark of *wu*. This was at 4 degrees in *Chang*."
> [*Chiu T'ang-shu*, 36]

[12]Some commentators, for example Stephenson (1997a), have interpreted phrases such as *Chih wei hou 1 k'o* as meaning "the 1st mark in the central half of the hour of *wei*." However, the practice of splitting the double hour into an initial and a central half did not come into general use until later times and a more likely reading is "after the 1st mark of the hour of *wei*," as I have given above. I am grateful to Dr. Liu Ciyuan of Shaanxi Observatory, China, for a helpful discussion of this issue.

Source	Date	Type	Contact	Local Time (h) Predicted	Observed	Computed
Sung-shu	434 Sep 4	Lunar	1	6.00	1.61	0.32
	434 Sep 4	Lunar	2	-	2.41	1.42
	437 Jan 8	Lunar	1	18.00	-	17.83
	437 Jan 8	Lunar	2	-	18.95	19.26
	437 Dec 28	Lunar	1	20.00	22.04	21.87
	437 Dec 28	Lunar	2	-	22.98	23.04
	438 Jun 23	Lunar	1	20.00	-	16.65
	440 Oct 26	Lunar	1	23.00	20.70	20.66
	440 Oct 26	Lunar	M	-	21.64	22.14
Sui-shu	585 Jan 21	Lunar	1	-	18.00	18.95
	585 Jan 21	Lunar	M	18.00	19.50	20.36
	585 Jan 21	Lunar	4	-	20.50	21.78
	585 Aug 1	Solar	1	-	12.68	14.51
	585 Aug 1	Solar	M	11.00	13.48	15.54
	585 Aug 1	Solar	4	-	14.32	16.47
	586 Jul 6	Lunar	M	18.00	-	21.63
	586 Dec 16	Solar	M	7.00	7.72	8.40
	590 Apr 25	Lunar	M	20.00	-	19.59
	590 Oct 19	Lunar	M	2.00	-	1.69
	592 Aug 28	Lunar	1	20.00	20.06	21.71
	593 Aug 17	Lunar	1	-	2.84	3.00
	594 Jul 23	Solar	1	-	13.84	14.54
	594 Jul 23	Solar	M	10.00	-	15.18
	595 Dec 22	Lunar	1	-	19.34	19.77
	595 Dec 22	Lunar	M	22.00	21.41	21.18
	595 Dec 22	Lunar	4	-	22.96	22.60
	596 Dec 11	Lunar	M	2.00	-	22.71
	596 Dec 11	Lunar	4	-	2.58	2.59
Chiu T'ang-shu	761 Aug 6	Solar	1	-	8.68	8.32
	761 Aug 6	Solar	M	-	9.48	9.60
	761 Aug 6	Solar	4	-	11.24	10.97
	768 Mar 23	Solar	M	-	11.48	12.81
Sung-shih	1168 Mar 26	Lunar	3	19.60	19.84	19.62
	1168 Mar 26	Lunar	4	20.84	20.84	20.65
	1173 Jun 12	Solar	1	-	12.32	12.36
	1173 Jun 12	Solar	M	-	13.60	14.12
	1173 Jun 12	Solar	4	-	15.36	15.59
	1185 Apr 18	Lunar	M	21.69	23.61	22.85
	1202 May 23	Solar	1	-	11.36	11.35
	1202 May 23	Solar	4	-	13.12	13.13
	1245 Jul 25	Solar	M	13.84	14.98	16.50

Table 6.13: Timed eclipse records in the *Sung-shu*, the *Sui-shu*, the *Chiu T'ang-shu*, and the *Sung-shih*.

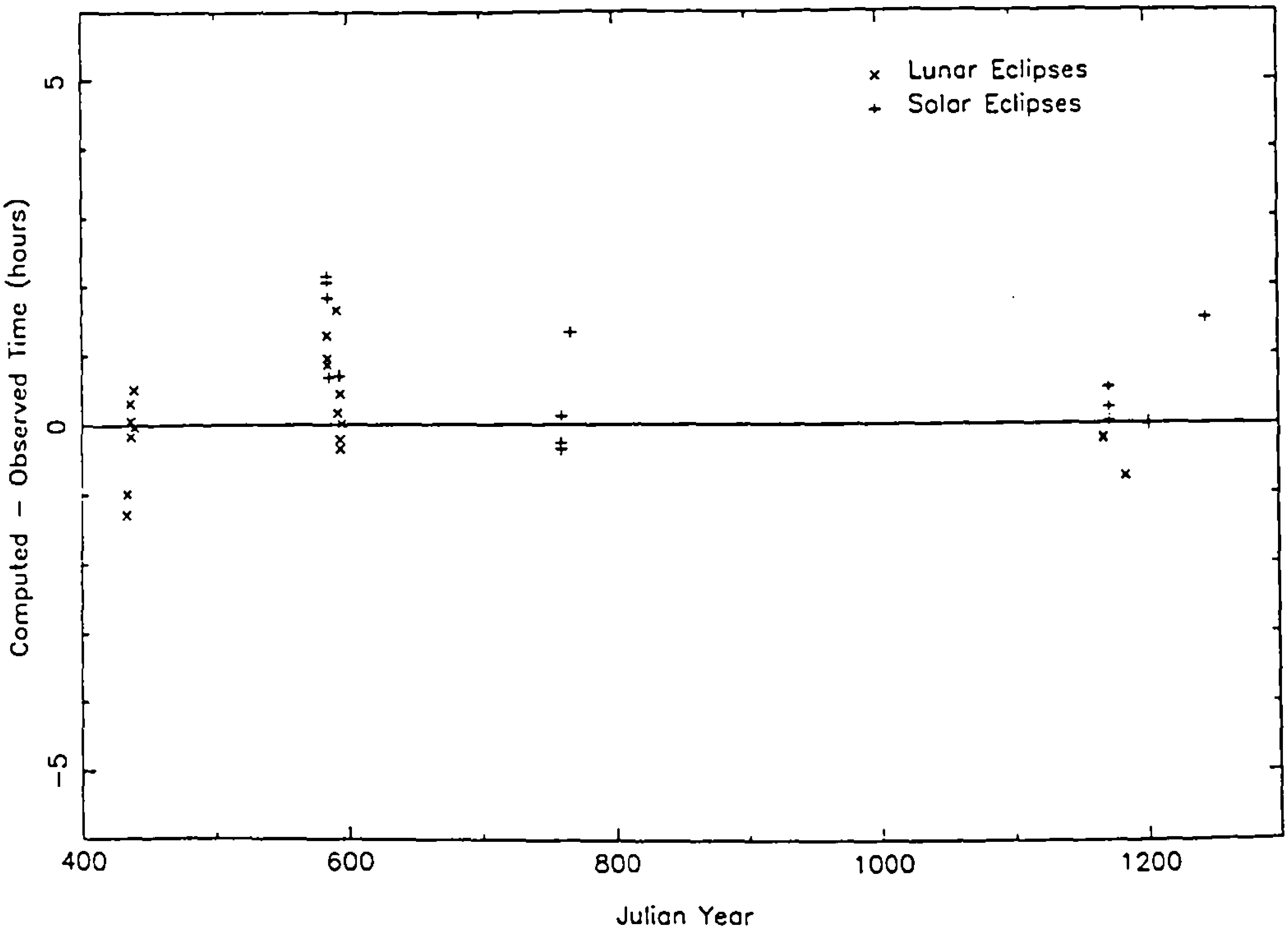


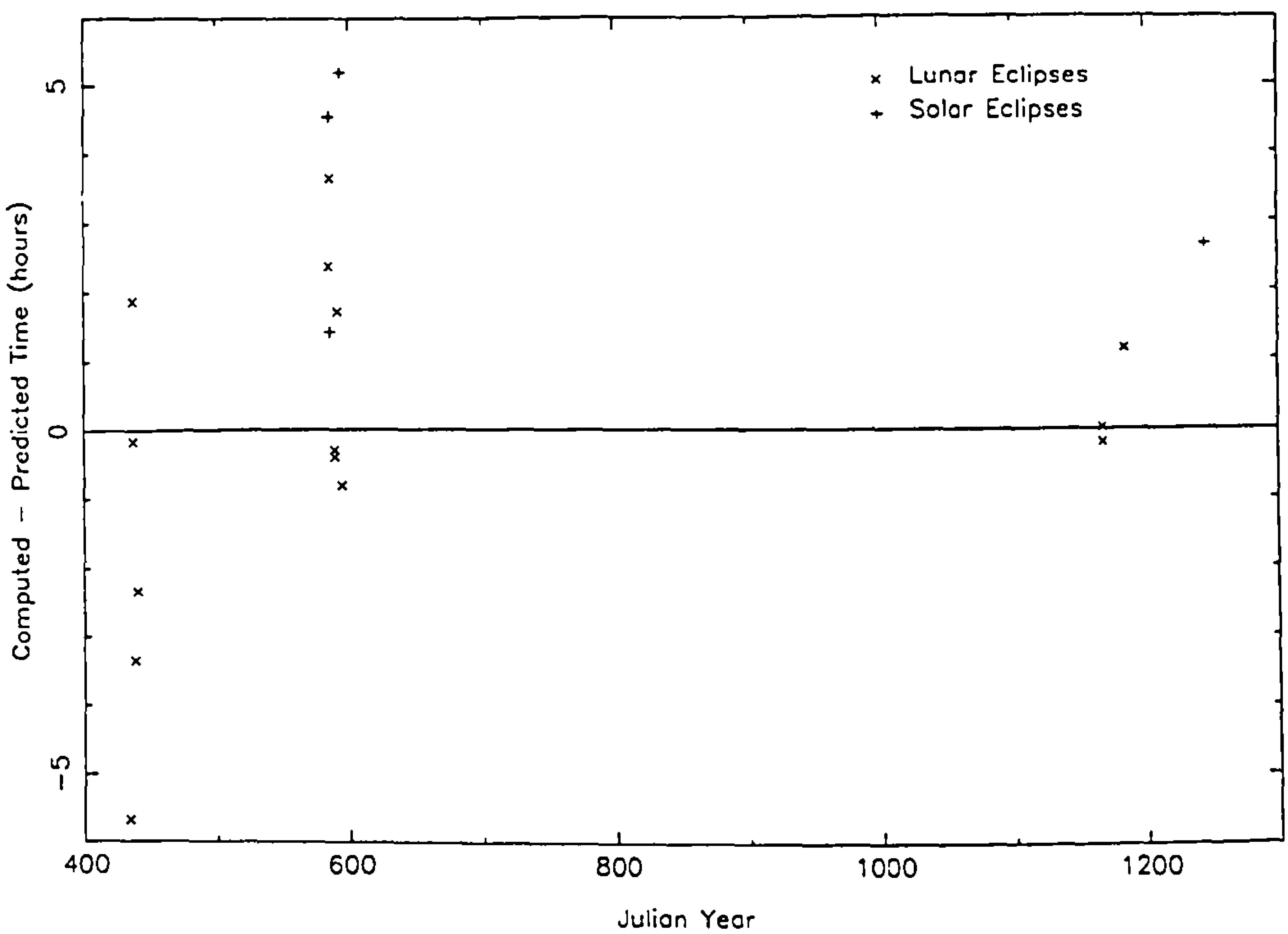
Figure 6.6: The error in the measured times of the eclipses in the *Sung-shu*, the *Sui-shu*, the *Chiu T'ang-shu*, and the *Sung-shih*.

- 26 March 1168 AD

> "Ch'ien Tao reign period, 4th year, 2nd month, the night of the full moon. At the 5th point of the 2nd watch the moon was eclipsed 9 divisions. It rose above the ground and returned to fullness. I ... said to the prime minister that the moon should have been totally eclipsed when it rose above the ground. The *Chi-yuan-li* also gave the eclipse as total when it rose above the ground. The light should have reappeared at the 2nd mark of the initial half of the hour of *hsu*, and it should have been returned to fullness at the 3rd mark of the central half of the hour of *hsu*. That evening, the moon was concealed by cloud at the time of moonrise. By the time of dusk, it was seen that the moon was already totally eclipsed. By the 3rd mark of the initial half of the hour of *hsu*, the shine had reappeared, and so we may know that the eclipse was total when it rose above the ground. It returned to fullness at the 3rd mark of the central half of the hour of *hsu*. This was at the 2nd point of the 2nd watch."
>
> [*Sung-shih*, 82]

The predicted and observed times of the various phases of the eclipses found in these sources, together with the times as deduced using modern computations, are given in Table 6.13. The errors in the observed times are shown in Figure 6.6. Clearly, there is no evidence for any systematic error in the timing of the eclipses from the Liu-Sung (c. AD 450), the T'ang (c. AD 760) or the Sung (c. AD 1200) dynasties. However, the eclipses observed during the Sui dynasty appear at first to be systematically early. This is mainly caused by the timings of the start, maximum, and end, of the eclipse on 1 August 585 AD. Presumably, a poorly calibrated clepsydra was used during this observation.

Figure 6.7 shows the errors in the predicted times of the eclipses given in these sources. These are shown both as the difference between the computed and the predicted times, which I have called



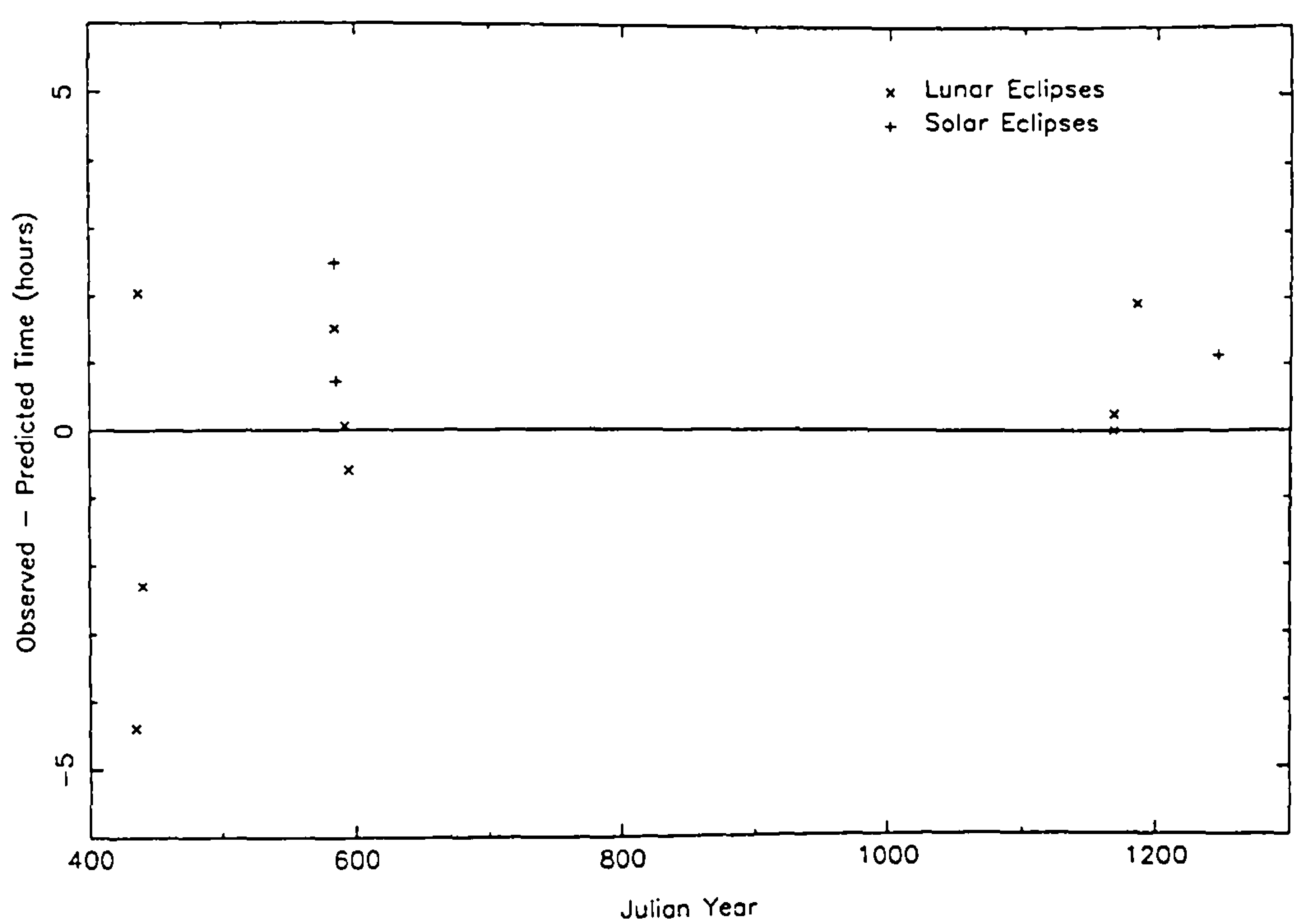


Figure 6.7: The true (above) and observed (below) errors in the predicted times of the eclipses in the *Sung-shu*, the *Sui-shu*, and the *Sung-shih*.

the "true" error as we evaluate it, and as the difference between the observed and the predicted times, which I have called the "observed" error as the contemporary Chinese astronomers would perceive it.

The five eclipses predictions from the *Sung-shu* were all made using the *Ching-ch'u-li* calendar. The mean observed accuracy of these predictions is about 2.9 hours, and the mean true accuracy is about 2.7 hours. The eclipses from the *Sui-shu* were predicted using the *K'ai-huang-li* calendar. They have a mean observed accuracy of about 1.8 hours, but a mean true accuracy of only about 2.3 hours. The first of the three predictions from the *Sung-shih* was made with the *Chi-yuan-li* and the second with the *Chung-hsi-li*; however, the name of the calendar used to make the third prediction is not given. This prediction is of significantly poorer accuracy than the other two eclipses. As there are so few records from this period, it is not possible to determine the accuracies of the individual calendars. However, the first and second two predictions seem to be of similar quality, and so it would seem that the Sung astronomers were making predictions to an observed accuracy of about 0.7 hours. The true accuracy of the Sung predictions is about 0.5 hours.

6.7.2 The *Yuan-shih*

The calendar treatise of the *Yuan-shih* contains more eclipse timings than all of the other sources put together in pre-Jesuit Chinese history. These are contained within a discussion of Kuo Shou-ching's *Shou-shih-li* calendar by Li Ch'ien. This discussion, entitled the *Shou-shih-li I*, forms chapters 52 and 53 of the *Yuan-shih*. An identical copy of the *Shou-shih-li I* is reprinted as chapters 38 and 39 of the *Hsin Yuan-shih*.

After comparing the calculation of the *Chieh-ch'i* by the *Shou-shih-li* with both observation and earlier calendars in chapter 52, Li Ch'ien devotes most of chapter 53 to discussing the reliability of the *Shou-shih-li* in calculating eclipses. To this end he compares the circumstances of eclipses observed over the preceding two thousand years of Chinese history, with those calculated by the *Shou-shih-li*.[13] Li Ch'ien also calculated the circumstances of the eclipses using the *Ta-ming-li* calendar, which had first been used about a century earlier, to show the superiority of the *Shou-shih-li* methods. The earlier records used by Li Ch'ien are the untimed solar eclipse observations recorded in the *Ch'un-ch'iu*. From about AD 400 onwards, however, he made use of detailed timed observations of both solar and lunar eclipses.

The records in the *Shou-shih-li I*, which are split into separate sections for solar and lunar eclipses, always give a detailed account of the date (including the dynasty and the cyclical year and day), the measured time of whichever of the eclipse contacts were observed, the corresponding times as calculated using the *Shou-shih-li* and the *Ta-ming-li*, and an assessment of the accuracy of the two systems. This is on a scale of five, ranging from *mi*, "exact", when there is no difference between the calculated and the observed time, to *shu yuan*, "far off", when the two times differ by 4 or more marks.

The eclipse records in the *Shou-shih-li I* are all set out in the same style. Full translations of all of the times eclipse records in the *Shou-shih-li I* are given in Appendix B. As examples, I give below translations of a solar and a lunar eclipse record:

[13]It is interesting to note that modern investigations into the variations in the Earth's rate of rotation using historical eclipse observations have an exact parallel with Li Ch'ien's investigation of seven hundred years ago. Although the fundamental goal of investigating the variations in the Earth's past rotation is to understand the physical processes that have caused it, an important consequence is in improving methods of eclipse calculation, both in the past and the future. This second goal is exactly the same as Li Ch'ien's.

Date	Contact	Local Time (h)			
		Shou-shih-li	*Ta-ming-li*	Observed	Computed
547 Feb 6	M	15.36	15.84	16.00	16.82
576 Jul 11	M	5.60	6.08	5.00	6.13
680 Nov 27	M	10.80	10.32	10.08	9.49
681 Nov 16	M	8.84	8.36	9.12	7.96
691 May 4	M	4.96	5.12	5.60	5.09
700 May 23	M	15.60	16.12	16.00	15.55
702 Sep 26	M	15.36	16.08	15.84	15.33
707 Jul 4	M	12.60	13.12	12.50	11.93
721 Sep 26	M	12.36	12.60	12.84	11.42
1046 Apr 9[2]	4	16.84	16.36	16.84	16.10
1049 Feb 5	M	11.84	12.12	12.50	12.14
1053 Nov 13[2]	M	13.84	13.12	13.36	13.88
1054 May 10[1]	M	16.36	16.60	16.36	16.55
1059 Feb 15[1]	4	13.60	13.60	13.84	14.16
1061 Jun 20[2]	1	13.12	13.36	13.50	13.20
1066 Sep 22	M	13.84	14.08	13.60	13.76
1069 Jul 21[2]	M	8.32	8.08	7.84	7.58
1080 Dec 14	M	10.32	9.60	10.56	10.01
1094 Mar 19[1]	M	14.32	14.32	14.56	15.09
1107 Dec 16	1	13.84	13.12	13.60	13.61
1107 Dec 16	M	15.12	14.80	14.96	15.23
1107 Dec 16	4	16.56	16.32	16.56	16.61
1162 Jan 17	1	15.36	14.80	15.50	15.54
1183 Nov 17	M	10.60	10.36	10.60	10.63
1195 Apr 12	1	11.36	11.60	11.60	11.67
1202 May 23	1	10.84	11.84	11.36	11.37
1216 Feb 19	M	16.84	16.60	16.98	16.91
1243 Mar 22	M	9.36	9.12	9.60	9.53
1260 Apr 12	M	16.36	15.84	16.60	16.56
1277 Oct 28	1	12.12	12.84	12.12	12.02
1277 Oct 28	M	13.33	14.36	13.36	13.34
1277 Oct 28	4	14.36	15.60	14.60	14.63

1. Eclipses with an identical observational record in another source.
2. Eclipses with an observational record that contradict another source.

Table 6.14: Timed solar eclipse records in the *Yuan-shih*.

- 27 November 680 AD

  "T'ang dynasty, Yung Lung reign period, 1st year, *keng-ch'en*, 11th month, *jen-shen*, first day of the month, (solar) eclipse maximum at the 4th mark of the hour of *ssu*. The *Shou-shih-li* gives the eclipse maximum at 7th mark of *ssu*. The *Ta-ming-li* gives the eclipse maximum at 5th mark of *ssu*. The *Shou-shih-li* is off. The *Ta-ming-li* is close."
  [*Yuan-shih*, 53]

- 28 January 948 AD

  "Later Han dynasty (of the 5 dynasties), T'ien Fu reign period, 12th year, *ting-wei*, 12th month, *i-wei*, full moon, (lunar) eclipse. Beginning of loss at the 4th point of the 4th watch. The *Shou-shih-li* gives the beginning of loss at the 5th point of the 4th watch. The *Ta-ming-li* gives the beginning of loss at the 1st point of the 4th watch. The *Shou-shih-li* is close. The *Ta-ming-li* is fairly close."
  [*Yuan-shih*, 53]

The solar and lunar eclipse times recorded in the *Shou-shih-li I* are summarized in Tables 6.14 and 6.15 respectively. Before making any conclusions about the accuracy of the eclipse predictions in the *Shou-shih-li I*, it is necessary to consider the reliability of the observational reports. A number of the observed eclipse times are recorded identically in other sources. These are noted by the superscript

		Local Time (h)			
Date	Contact	*Shou-shih-li*	*Ta-ming-li*	Observed	Computed
434 Sep 4[1]	1	2.01	1.61	1.61	0.32
434 Sep 4[1]	2	2.41	2.81	2.41	1.42
437 Jan 8[1]	2	18.95	19.45	18.95	19.26
437 Dec 28[1]	1	22.47	21.96	21.96	21.87
437 Dec 28[1]	2	23.49	23.49	22.98	23.04
543 May 4	1	23.26	0.00	0.00	23.81
592 Aug 28[1]	1	20.46	20.85	20.06	20.35
595 Dec 22[1]	1	18.82	19.85	19.34	19.77
595 Dec 22[1]	M	20.89	21.41	21.41	21.18
595 Dec 22[1]	4	22.44	22.44	22.96	22.60
596 Dec 11[1]	4	3.09	3.60	2.58	2.59
948 Jan 28	1	3.43	1.47	2.94	3.64
1052 Dec 8	1	3.60	3.36	4.08	4.29
1063 Nov 8[1]	M	7.12	7.12	6.80	7.32
1069 Dec 30[2]	1	22.56	23.12	22.56	22.95
1069 Dec 30[2]	M	0.32	0.56	0.32	0.45
1069 Dec 30[2]	4	1.84	2.08	2.08	1.95
1071 Dec 9[1]	1	5.12	6.08	5.60	5.34
1071 Dec 9[1]	M	6.32	6.80	6.56	6.47
1073 Apr 24[1]	1	20.80	21.60	21.36	21.26
1073 Apr 24[1]	M	22.32	22.80	22.56	22.60
1073 Apr 24[1]	4	23.84	0.08	0.08	23.95
1074 Oct 7[2]	1	2.88	2.06	2.88	3.29
1074 Oct 7[2]	2	4.12	3.70	4.12	4.36
1106 Jan 21	M	17.36	17.84	17.84	17.61
1106 Jan 21	4	18.80	19.60	19.12	19.09
1270 Apr 7	1	1.60	2.08	1.84	1.32
1270 Apr 7	M	3.12	3.36	3.12	2.83
1270 Apr 7	4	4.56	4.80	4.56	4.35
1272 Aug 10	1	0.80	1.60	1.12	0.91
1272 Aug 10	M	2.08	2.56	2.56	2.18
1272 Aug 10	4	3.60	3.60	3.84	3.47
1277 May 18	1	0.56	1.12	0.56	0.61
1277 May 18	2	2.08	2.80	1.84	1.70
1277 May 18	M	2.32	2.80	-	2.31
1277 May 18	3	2.56	2.96	2.80	2.92
1277 May 18	4	4.08	4.56	4.08	4.01
1279 Mar 29	1	0.32	0.80	0.32	0.31
1279 Mar 29	M	1.60	1.84	1.60	1.43
1279 Mar 29	4	2.80	2.80	2.80	2.56
1279 Oct 21	1	1.84	2.80	2.32	2.38
1279 Oct 21	M	3.12	3.60	3.12	3.24
1279 Oct 21	4	4.08	4.08	4.08	4.10
1280 Oct 10	4	19.36	20.08	19.36	19.53

1. Eclipses with an identical observational record in another source.
2. Eclipses with an observational record that contradict another source.

Table 6.15: Timed lunar eclipse records in the *Yuan-shih*.

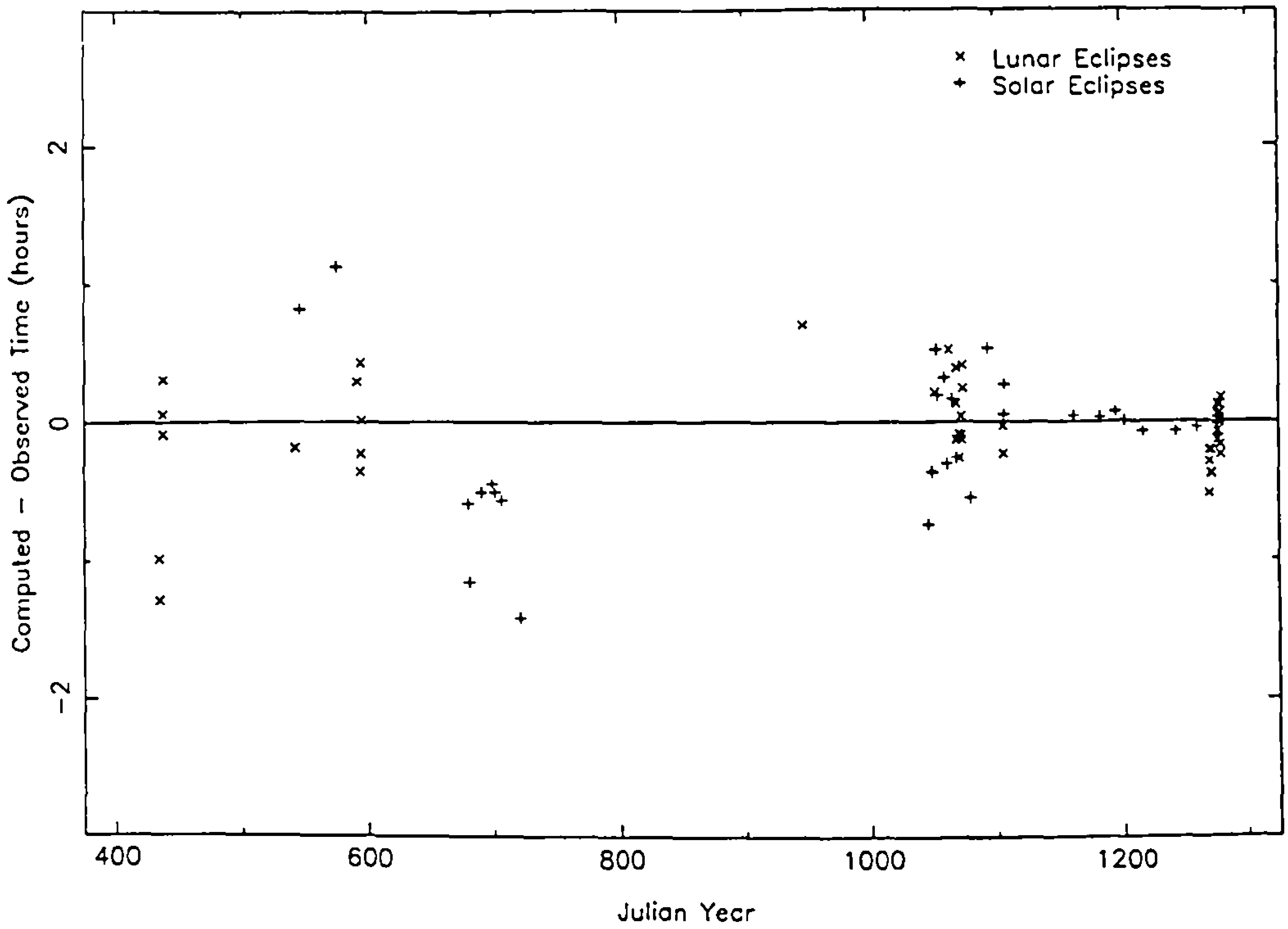


Figure 6.8: The error in the measured times of the eclipses in the *Yuan-shih*.

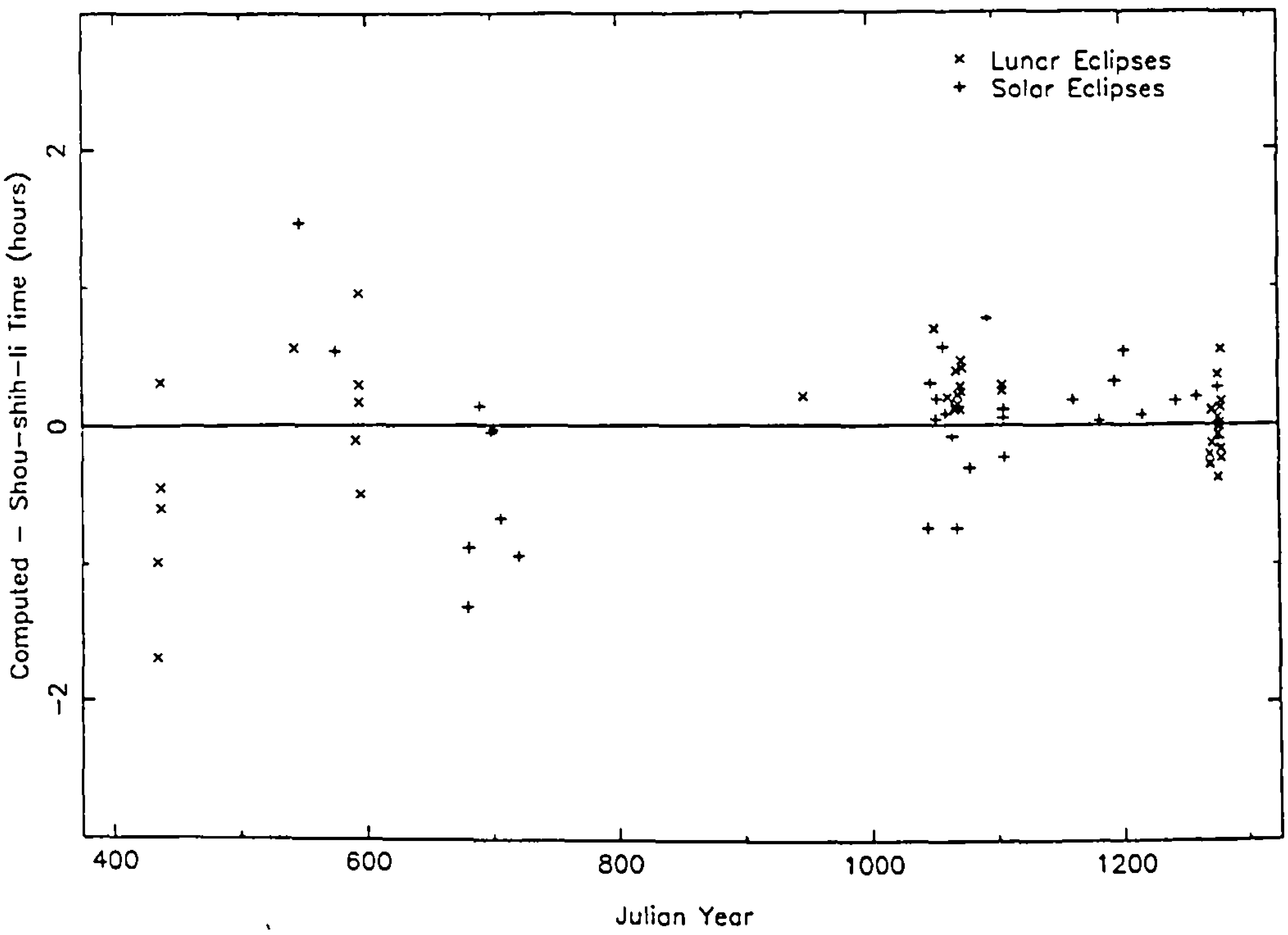
1 to the dates in the Tables. However, a small number of the eclipses, indicated by the superscript 2, contradict the reports given in other sources. The solar eclipses in AD 1061 and AD 1069 are said in the astrological treatise of the *Sung-shih* to have not been seen. However, in the light of the remarks made above about the general reliability of the astrological treatise as an observational record, I choose to accept the detailed reports in the *Shou-shih-li I* as being the more genuine accounts of the observations. In addition, the AD 1061 eclipse is recorded as having been observed in the *Wen-hsing T'ung-k'ao*.

The times of the solar eclipses in AD 1046 and AD 1053, and the lunar eclipses in AD 1069 and AD 1074, contradict those given in the *Wen-hsien T'ung-k'ao*. However, the errors in the times given in the *Shou-shih-li I* are much smaller, and are of comparable size to contemporary records, than those given in the *Wen-hsien T'ung-k'ao*. Therefore, I shall consider the *Shou-shih-li I* reports as genuine, and the contradictory times in the *Wen-hsien T'ung-k'ao* as anomalous. These anomalous timings will be discussed further in Section 6.7.3 below.

There are no records of the times of the other eclipses in any other available source. This has led Cohen & Newton (1983) to suggest that they may not be observed times, but rather calculated times given by an unknown calendar system. However, this view clearly comes from a misunderstanding of the nature of the *Shou-shih-li I*; it would have been meaningless for Li Ch'ien to have compared two calendar systems with a third to try and show that one was more accurate than the other. It is much more likely that these observed times were recorded in a source that was available to the Yuan astronomers, but which has now been lost.[14]

The error in the observed times of the eclipses recorded in the *Shou-shih-li I* are shown in Figure 6.8. Clearly, there is no evidence for any systematic error in the observed times. Around AD 1200, there are a number of solar eclipse timings which appear to be significantly more accurate than the

[14]Or, at least, is not among the limited collection of work that is known of and is available to modern scholars.



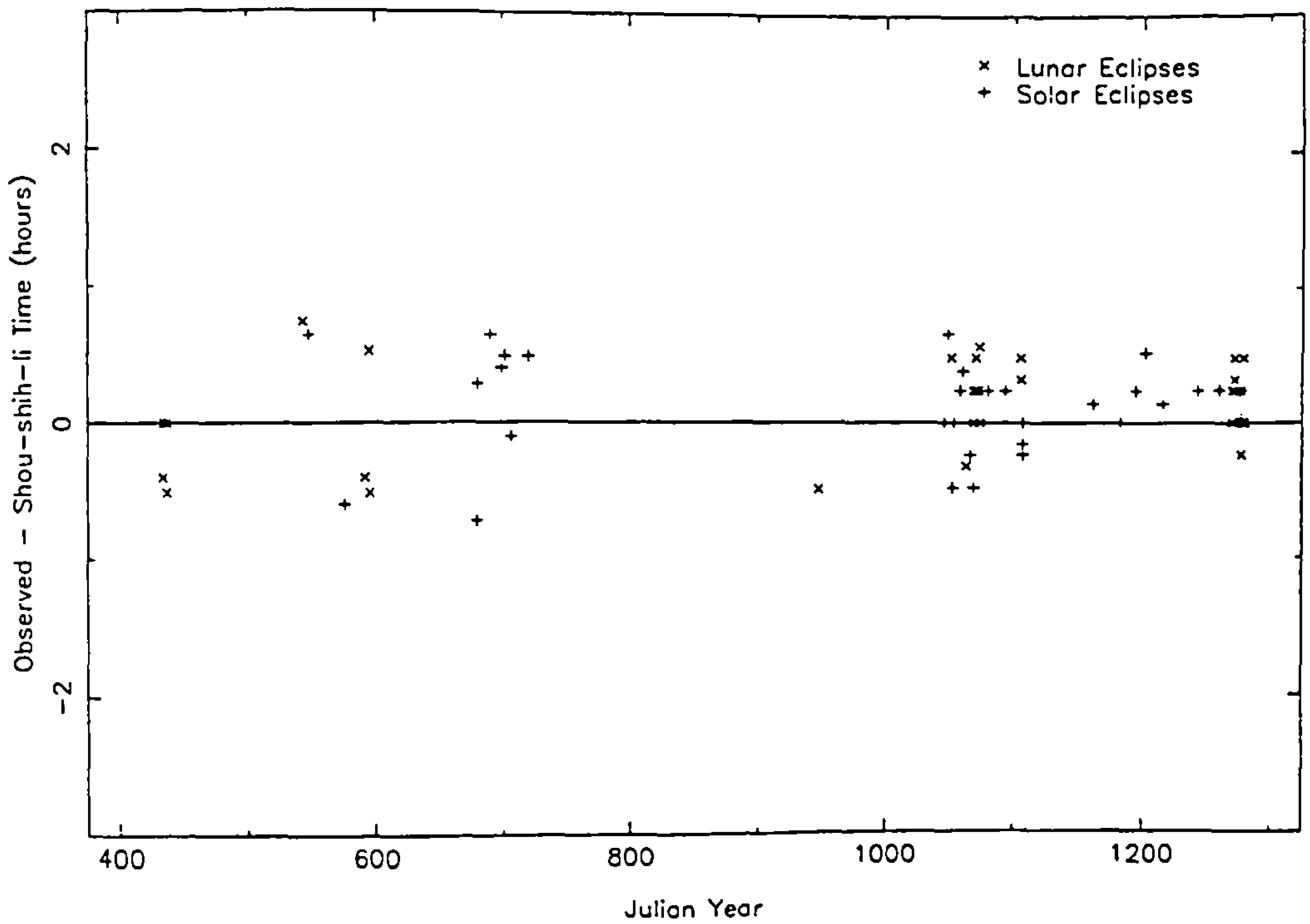
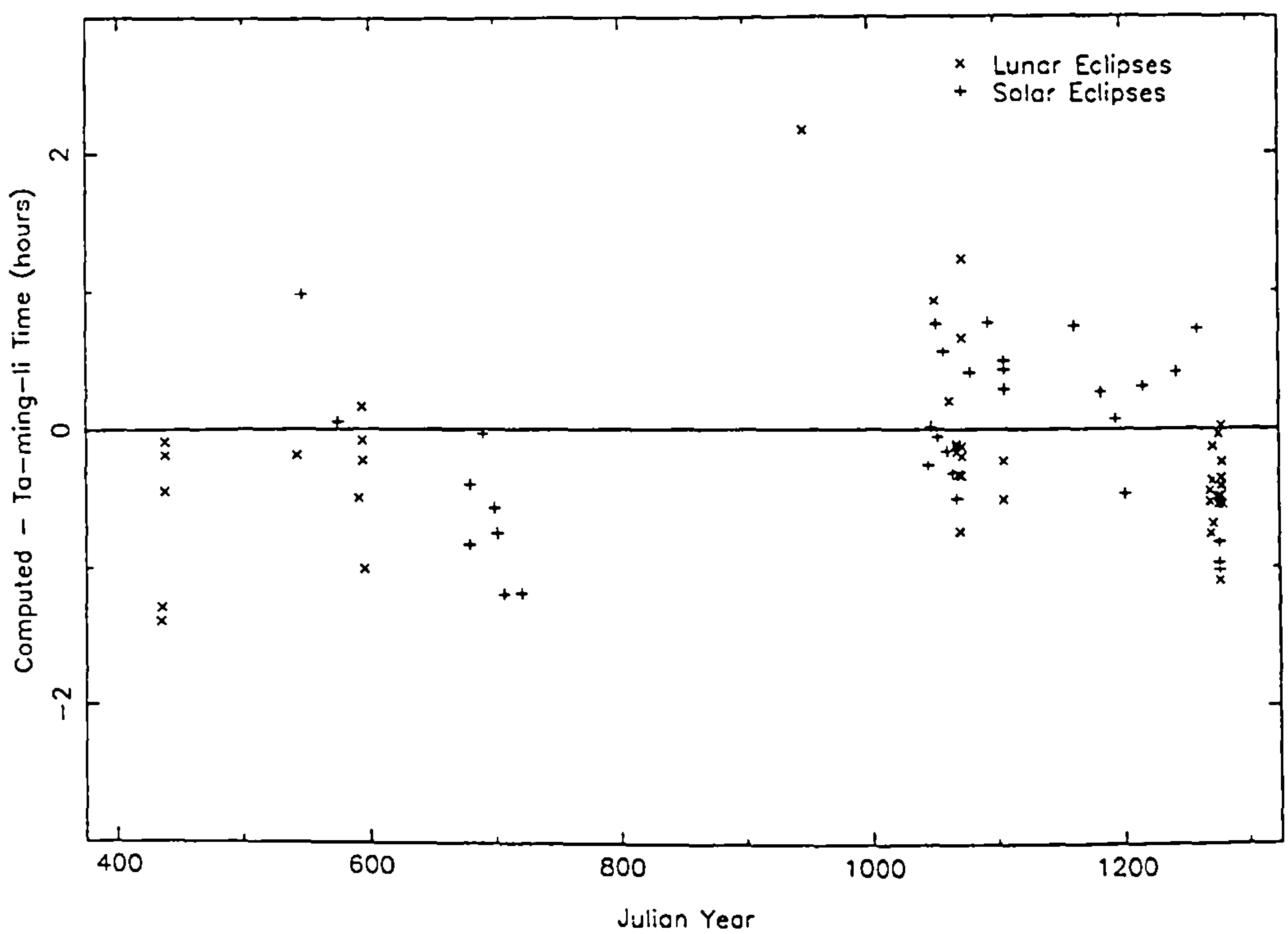


Figure 6.9: The true (above) and observed (below) errors in times predicted using the *Shou-shih-li*.



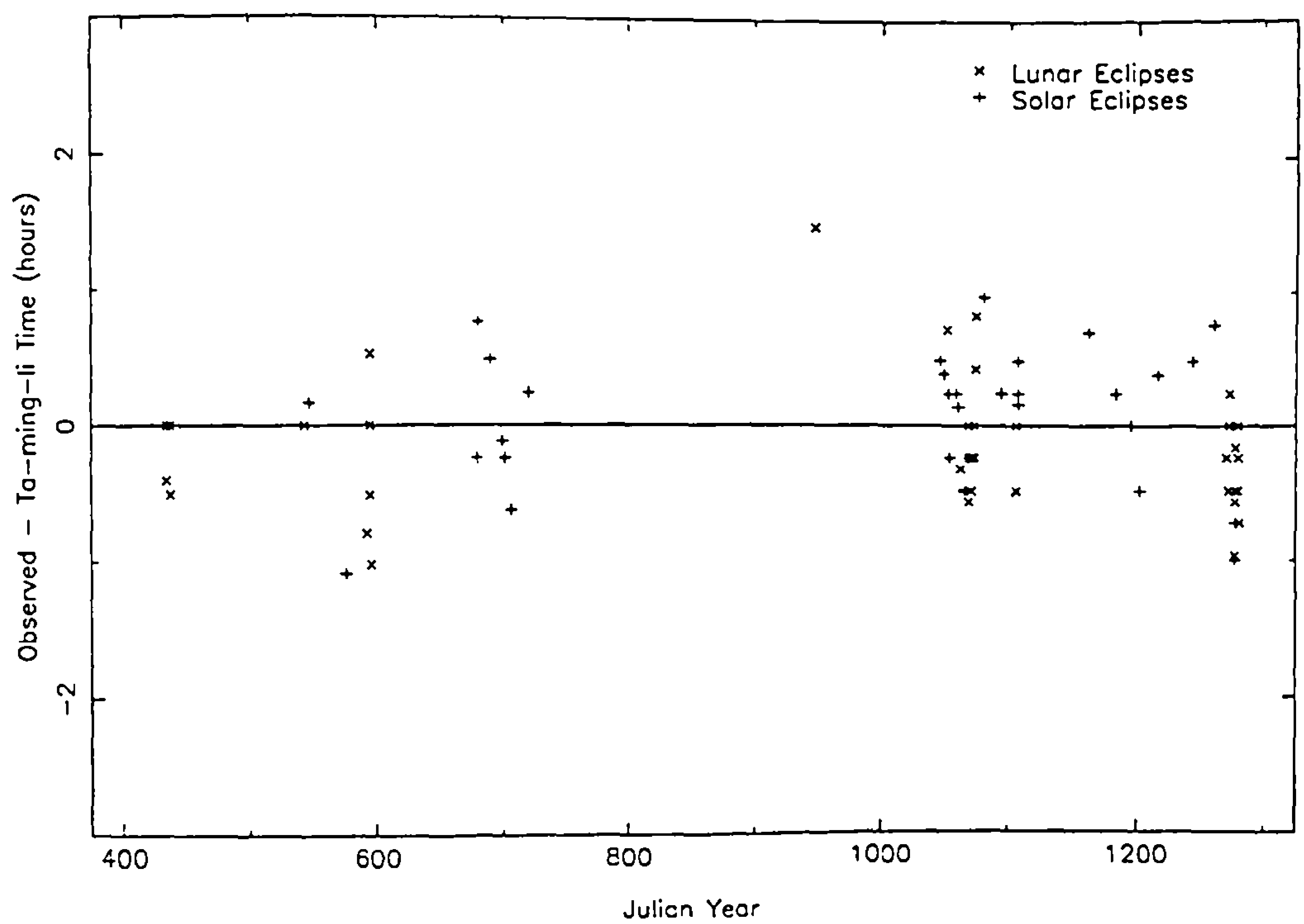


Figure 6.10: The true (above) and observed (below) errors in times predicted using the *Ta-ming-li*.

eclipses from other periods.

Figure 6.9 shows the error in the times calculated using the *Shou-shih-li* calendar. There is no evidence for any change in the accuracy with which the calendar could predict the times of eclipse contacts with year. It might have been expected that the earlier predictions would be less accurate than those made around the epoch of the calendar as the small inaccuracies in the parameters used by the calendar would accumulate over time. Evidently, these inaccuracies were sufficiently small to be negligible over about one thousand years. This is a considerable achievement. The mean true accuracy of the *Shou-shih-li* in calculating the times of eclipses over the whole of this period is about 0.34 hours. The mean observable accuracy is about 0.27 hours.

The errors in the times calculated using the *Ta-ming-li* are shown in Figure 6.10. Once more, there is no evidence for any decrease in accuracy of the calendar as it was used further back in time. The mean true accuracy of the *Ta-ming-li* in calculating the times of eclipses is about 0.50 hours over the whole of the period from AD 200 to AD 1300. The mean observable accuracy is about 0.41 hours.

6.7.3 The *Wen-hsien T'ung-k'ao*

The *Wen-hsien T'ung-k'ao*, an encyclopedia compiled by Ma Tuan-lin in AD 1307, contains a number of timed observations of both solar and lunar eclipses. However, in no cases are any predicted times of the eclipses reported. The solar eclipses are contained in chapter 283, whilst the lunar eclipses are in chapter 285. They mainly date from the latter half of eleventh century AD, although there are two solar eclipses form the AD 1040's. I give below in translation an example of a lunar and a solar eclipse reported in this work. Full translations of all of the eclipse records in the *Wen-hsien T'ung-k'ao* are given in Appendix B.

- 19 March 1094 AD

> "[Yuan Yu reign period,] 9th year, 3rd month, *jen-shen*. On the 1st day of the month, according to the Astronomer Royal, the Sun should have been eclipsed, but on account of thick clouds it was not seen. The loss began (to be seen) at the 3rd mark of *wei*. It was seen through the clouds that the Sun was eclipsed on the south-western side in excess of 1 division. At the 6th mark it reached a maximum of 7 divisions. On account of the clouds, its recovery was not seen."
> [*Wen-hsien T'ung-k'ao*, 283]

- 9 December 1071 AD

> "[Hsu Ning reign period, 4th year,] 11th month, *ping-shen*. The Moon was eclipsed at the 2nd mark of *mao*. The loss passed from the south-east side to the west side. At the 6th mark, the eclipse reached its maximum of $4\frac{1}{2}$ divisions. This was at 1 degree in *tung-ching*. As dawn broke, the Moon set, and the end of the eclipse could not be discerned."
> [*Wen-hsien T'ung-k'ao*, 285]

The timed eclipse records from the *Wen-hsien T'ung-k'ao* are given in Table 6.16. As noted above, a small number of these observations are also reported in the *Yuan-shih* calendar treatise, in some cases with contradictory details. The records that give the same details are denoted by the superscript 1 to the date. Those that contradict the *Yuan-shih* report have the superscript 2. The error in the measured times of these eclipses is shown in Figure 6.11.

The fact that a number of the reports in the *Wen-hsien T'ung-k'ao* contradict those in the calendar treatise of the *Yuan-shih* suggests that Li Ch'ien and Ma Tuan-lin obtained their eclipse reports from different sources. This is not as surprising as it may at first seem, for there were two astronomical observatories operating at the capital during the eleventh century AD. In addition to the Bureau of Astronomy and Calendar, the Astronomical Department of the Imperial Academy was established

Date	Type	Contact	Local Time (h) Observed	Computed
1040 Feb 15	Solar	4	15.36	15.88
1046 Apr 9[2]	Solar	4	15.84	16.11
1052 Nov 24	Solar	4	13.36	15.00
1053 Nov 13[2]	Solar	M	12.36	13.89
1054 May 10[1]	Solar	M	16.36	16.55
1059 Feb 15[1]	Solar	4	13.84	14.17
1061 Jun 20	Solar	M	13.36	14.52
1063 Nov 8[1]	Lunar	M	6.80	7.32
1067 Mar 3	Lunar	1	2.08	4.92
1067 Mar 3	Lunar	M	2.56	6.79
1068 Aug 15	Lunar	1	2.32	4.92
1069 Dec 30[2]	Lunar	1	21.36	22.95
1069 Dec 30[2]	Lunar	M	23.12	0.45
1069 Dec 30[2]	Lunar	4	23.84	1.95
1071 Dec 9[1]	Lunar	1	5.36	5.35
1071 Dec 9[1]	Lunar	M	6.56	6.47
1073 Apr 24[1]	Lunar	1	21.36	21.26
1073 Apr 24[1]	Lunar	M	22.56	22.61
1073 Apr 24[1]	Lunar	4	0.08	23.95
1073 Oct 18	Lunar	1	2.08	4.28
1073 Oct 18	Lunar	M	2.56	7.12
1074 Oct 7[2]	Lunar	1	1.36	3.29
1074 Oct 7[2]	Lunar	M	2.56	5.24
1077 Feb 10	Lunar	1	23.84	1.47
1077 Feb 10	Lunar	M	0.80	3.08
1077 Feb 10	Lunar	4	1.84	4.69
1078 Jan 30	Lunar	1	2.32	1.83
1078 Jul 27	Lunar	2	19.60	19.34
1078 Jul 27	Lunar	4	21.84	21.83
1081 May 25	Lunar	4	20.56	17.51
1082 Nov 8	Lunar	1	17.60	17.75
1082 Nov 8	Lunar	M	18.80	18.80
1082 Nov 8	Lunar	4	19.84	19.85
1085 Sep 6	Lunar	1	19.84	19.56
1085 Sep 6	Lunar	2	20.80	20.51
1085 Sep 6	Lunar	4	23.36	23.10
1088 Jul 6	Lunar	1	22.32	22.18
1088 Jul 6	Lunar	2	0.58	23.49
1088 Jul 6	Lunar	4	2.08	1.80
1089 Jun 25	Lunar	4	2.56	2.55
1092 Apr 24	Lunar	1	21.36	21.24
1092 Apr 24	Lunar	2	22.80	22.18
1092 Apr 24	Lunar	4	0.80	0.77
1094 Mar 19[1]	Solar	M	14.56	15.10
1097 Jan 30	Lunar	M	19.36	19.34
1099 Jun 5	Lunar	1	23.84	23.82
1099 Jun 5	Lunar	2	1.60	0.93
1099 Jun 5	Lunar	4	3.60	3.46
1099 Nov 30	Lunar	1	22.08	22.10
1099 Nov 30	Lunar	2	0.08	23.14
1099 Nov 30	Lunar	4	2.08	1.84

1. Eclipses with an identical observational record in the *Yuan-shih*.
2. Eclipses with a contradictory observational record in the *Yuan-shih*.

Table 6.16: Timed eclipse records in the *Wen-hsien T'ung-k'ao*.

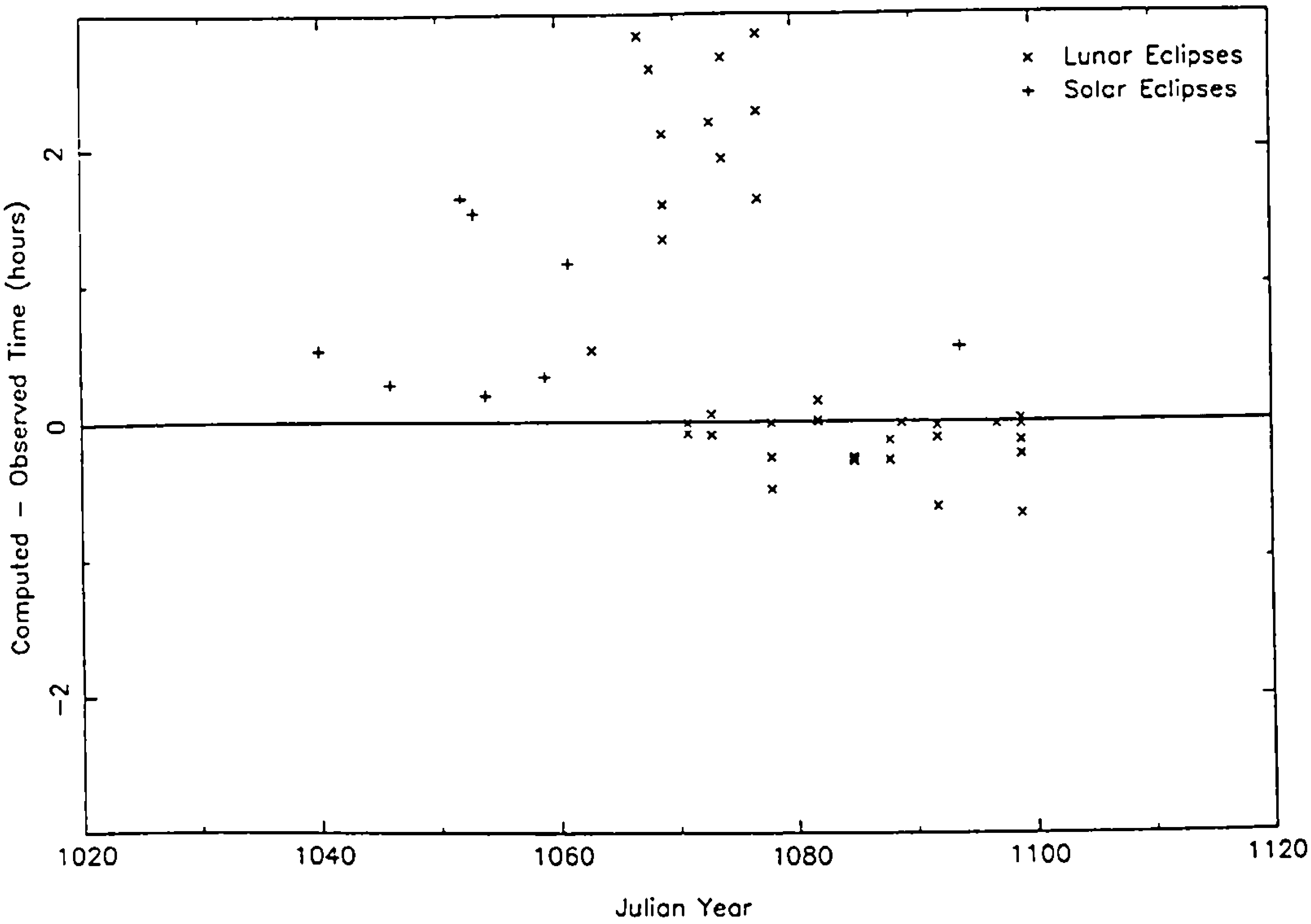


Figure 6.11: The error in the measured times of the eclipses in the *Wen-hsien T'ung-k'ao*.

within the Imperial Palace. These two institutions were instructed to observe independently and then to report to the Palace every morning to compare their results. This was supposed to avoid false reports. However, as P'eng Ch'eng wrote in his *Mo-k'o Hui-hsu*, by about AD 1050, "the officials of the two observatories secretly copied from each other before reporting, and this went on for years."[15] Between AD 1068 and AD 1077, P'eng Ch'eng held the position of Astronomer Royal. One of his main acts was to expose the officials who had perpetrated this deception. This may account for the fact that of the five eclipses reported in the *Wen-hsing T'ung-k'ao* that were observed during his tenure, in two cases the reports contradict those in the *Yuan-shih*. These cannot all simply be put down to scribal errors — the eclipse in AD 1074 was timed in double hours and marks in the report contained in the *Wen-hsing T'ung-k'ao*, but in fifths of a night watch in the *Yuan-shih* report. Thus, it seems very likely that the eclipse records in the *Yuan-shih* and in the *Wen-hsien T'ung-kao* come from two different sources, probably the two observatories.[16]

Now that we have established a plausible reason why contradictory reports of eclipses might be found in different sources, we must ask how it is possible that the two sets of observers apparently made measurements of the times of the eclipses that were so widely different. In many cases the recorded times can vary by an hour or more. However, two observers, at most a mile apart and presumably using similar clepsydras, would not measure the time of an event to be different by, say, more than a mark, and so there must be another explanation. I will therefore examine each of the contradictory reports in turn to try to find one.

[15] *Mo-k'o Hui-hsu*, 7; trans. Needham, Wang, & de Solla Price (1960: 16).

[16] We might speculate that the records in the *Yuan-shih*, which were compiled by an author involved in calendar reform, are more likely to have come from the Bureau of Astronomy and Calendar where he presumably worked, and the records in the *Wen-hsien T'ung-k'ao* to have come from the Astronomical Department of the Imperial Academy. However, there is no firm evidence either way.

- 2 April 1046 AD

> "It was returned (to fullness) at the 3rd mark of *shen*." [*Wen-hsien T'ung-k'ao*, 283]
> "Return to fullness at the 3rd mark of the central half of *shen*." [*Yuan-shih*, 53]

The simplest explanation in this case is that the character *cheng*, indicating the central half of the hour, has been missed by a careless scribe. However, recalling the sunrise and sunset times from chapter 70 of the *Sung-shih*, it is possible that the convention of counting the marks within a double hour from the middle, rather than the start, of each double hour was being used. Either explanation is quite plausible.

- 13 November 1053 AD

> "... at the 1st mark of the central half of *wu*, (the Sun) was eclipsed by $4\frac{1}{2}$ divisions." [*Wen-hsien T'ung-k'ao*, 283]
> "Eclipse maximum at the 1st mark of the hour of *wei*." [*Yuan-shih*, 53]

In this case it is possible that either of the records could contain a scribal error and that the time of the middle of the eclipse could be either at the 1st mark of *wei*, or at the 1st mark of the central half of *wu*.

- 30 December 1069 AD

> "At the 1st mark of *hai*, the loss was seen on the north-eastern side. At the initial mark of *tzu*, the eclipse reached its maximum ... At the 3rd mark, it was returned to fullness." [*Wen-hsien T'ung-k'ao*, 285]
> "Beginning of loss at the 6th mark of *hai*. Maximum at the 5th mark of *tzu*. Return to fullness at the 4th mark of *ch'ou*." [*Yuan-shih*, 53]

If we interpret the 1st mark of *hai* as the 1st mark in the central half of *hai*, then the time of the start of the eclipse is 22.36 hours. This is close to the time given in the *Yuan-shih* of 22.56 hours. A difference of 0.20 hours (12 minutes) is quite possible when two observers are measuring the time to the nearest mark (14.4 minutes). Similarly, if for the time of the middle of the eclipse, the initial mark of *tzu* is interpreted as being the initial mark in the central half of *tzu* (i.e. 0.12 hours), it is close to the time of 0.32 hours given in the *Yuan-shih*. The time of the end of the eclipse recorded in the *Wen-hsien T'ung-k'ao* cannot be reconciled with this time given in the *Yuan-shih* by this method. However, this time is also inconsistent with the other times reported in the *Wen-hsien T'ung-k'ao* — the time from the beginning of the eclipse to the middle is 7 marks, but the time from the middle to the end is only 3 marks.

- 7 October 1074 AD

> "At the 1st mark of *ch'ou* the loss began on the eastern side. At the 6th mark, the eclipse reached its maximum ... Dawn broke and its return to fullness was not seen." [*Wen-hsien T'ung-k'ao*, 285]
> "Beginning of loss at the 5th point of the 4th watch. Eclipse total at the 3rd point of the 5th watch." [*Yuan-shih*, 53]

According to the report in the *Wen-hsien T'ung-k'ao*, the end of the eclipse was not seen on account of dawn breaking. If the times given in the report are accepted at face value then the eclipse started at 1.36 and reached its maximum at 2.56. Thus the end of the eclipse cannot have been much after 4 am. However, the Moon did not set until about 5.45, and the Sun did not rise until 6.28. Therefore we cannot accept the recorded times as they are. If we once more assume

Date	Type	Contact	Local Time (h) Observed	Computed
1068 Feb 6	Solar	1	10.96	11.11
1068 Feb 6	Solar	M	12.44	12.41
1068 Feb 6	Solar	4	13.84	13.66
1100 May 11	Solar	4	10.84	10.11
1572 Jul 10	Solar	1	6.84	6.68
1572 Jul 10	Solar	4	9.84	9.41
1577 Apr 2	Lunar	1	2.84	2.09
1578 Mar 23	Lunar	1	20.84	19.32
1587 Mar 24	Lunar	4	22.84	21.55
1596 Oct 22	Solar	1	10.60	9.89
1596 Oct 22	Solar	M	12.98	11.19
1610 Dec 15	Solar	1	14.36	14.61
1610 Dec 15	Solar	M	15.60	16.07
1610 Dec 15	Solar	4	17.60	17.32
1617 Feb 20	Lunar	1	19.60	18.56
1617 Feb 20	Lunar	M	19.84	20.47

Table 6.17: Timed eclipse records in other sources.

that the marks were measured from the middle rather than the start of the double hour, however, then the eclipse would have started at 2.36, reached it maximum at 3.56, and so ended sometime around 5 am. Thus it is just conceivable that the Moon might have set, or at least been very close to the horizon, when the eclipse ended. Furthermore, within this assumption, the times are quite close to those given in the *Yuan-shih* (2.88 hours for the beginning of the eclipse and 4.12 hours for the beginning of totality). Discrepancies of this magnitude are consistent with our hypothesis of two different observers.

Three of the four cases outlined above seem to indicate that it is at least plausible, and indeed probable, that the marks were measured from the middle rather than the start of the double hour, in the same fashion as in the sunrise and sunset times in the *Sung-shih* discussed earlier. This may account for the fact that some of the other eclipses in the period from about AD 1065 to AD 1080 are also appear to be systematically early. However, in some of these cases the times are early by as much as four or five hours. Clearly these cases must be due to scribal errors.[17] Of course, not all of the eclipses times at this period use this system. For example, the eclipses in AD 1071 and AD 1073, which have an identical record in the *Yuan-shih*, obviously do not. This suggest two possibilities: either the original records contained a mix of timings in this unusual system and in the normal system, or all of the timings were in the unusual system, and Ma Tuan-lin converted them to the normal system, but inadvertently missed a small number. It is impossible to tell which it was.

6.7.4 Other Sources

A further nine timed eclipse observations in other pre-Jesuit sources have been uncovered by Beijing Observatory (1988). Two of these, recorded in the *Sung-hui-yao Chi-k'ao*, date from the Sung dynasty; the others are all from the Ming dynasty. They are listed in Table 6.17. The errors in the observed times are shown in Figure 6.12. Full translations of these records are given in Appendix B.

[17] Despite P'eng Ch'eng's comment that the astronomers in the observatories "contented themselves with copying out the positions of the Sun, Moon, and planets according to very rough ephemerides ... never using the (astronomical equipment in the) observatory" [*Mo-k'o Hua-hsi*, 7; trans. Needham, Wang & de Solla Price (1986: 16)], these very inaccurate times cannot have been calculated. The Sung calendars were able to predict the time of an eclipse to at least within an hour. Furthermore, calculating an eclipse time using these methods is not an easy task — certainly requiring more effort than actually observing the eclipse.

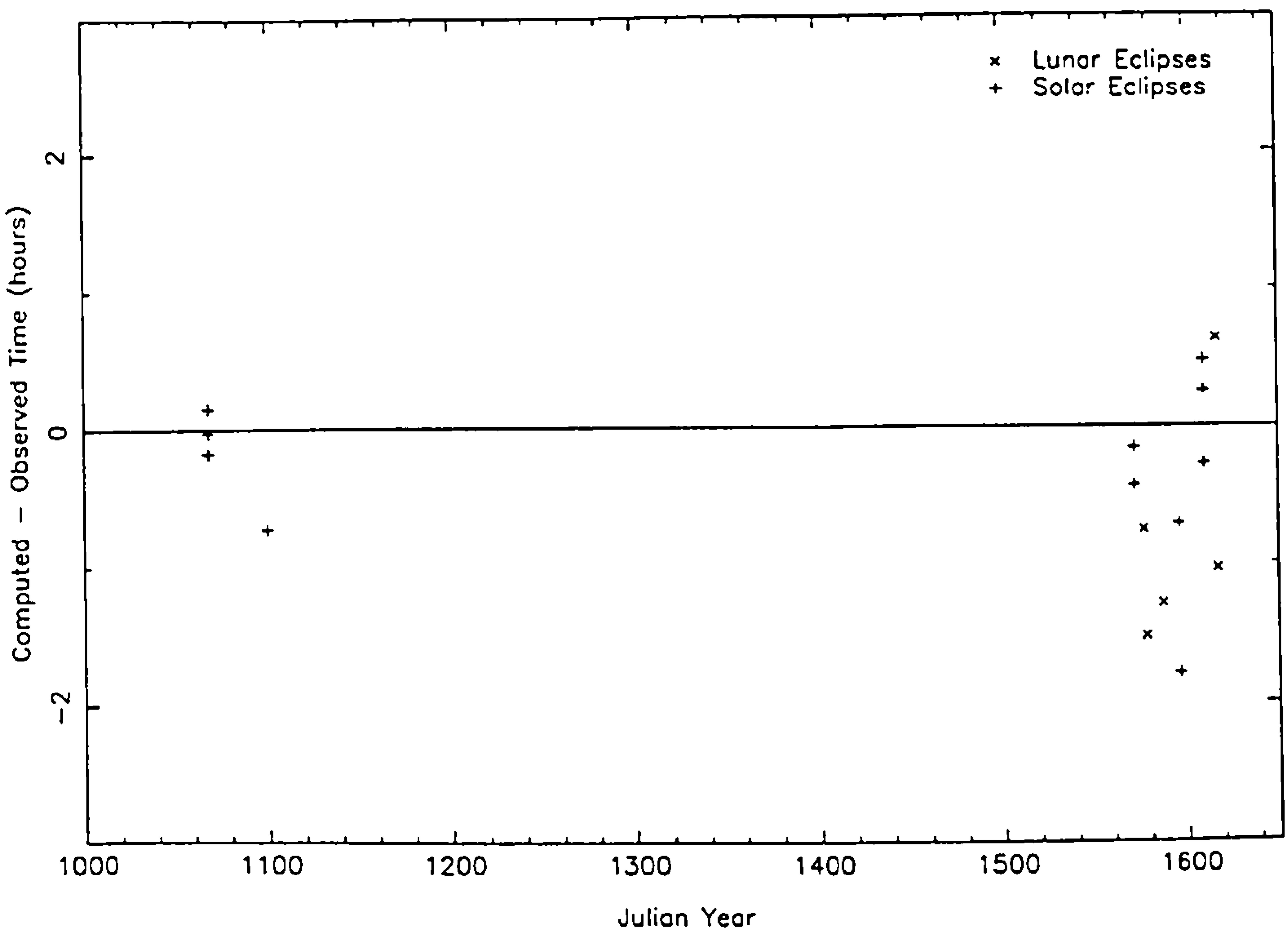


Figure 6.12: The error in the measured times of the eclipses mentioned other sources.

6.8 Accuracy of the Observed Times

Having outlined the all of the available measurements of eclipse times, it is now possible to study them as a whole. I have accepted the corrections to the anomalous timings in the *Wen-hsien T'ung-k'ao* that I have considered plausible in Section 6.7.3 above. However, as some of the other measurements in the *Wen-hsien T'ung-k'ao* for which there is no firm evidence for making such corrections are in error by large amounts, I have discarded any observations with an error of greater than two hours from the following analysis.

Looking first at the solar eclipse records, Figure 6.13 shows the error in all of the measured times. There is no evidence for any systematic error over the whole of the period from about AD 500 to AD 1625; this provides further proof that the assumption that the small mark is at the end of the double or half double hour, made in Section 6.5 above, is correct. The mean accuracy of the solar eclipse timings is about 0.41 hours over the whole of this period. Between about AD 1090 and AD 1300 there appears to be a some improvement in the accuracy of the timings; the mean accuracy of the records at this period is about 0.16 hours.

Figure 6.14 shows the error in all of the measured times of lunar eclipses. The mean accuracy of the lunar eclipse timings over the whole of the period from about AD 400 to AD 1625 is about 0.52 hours. Once more, there appears to be an improvement in accuracy in the period from about AD 1090 to AD 1350; the mean accuracy of these timings is about 0.21 hours. Surprisingly, there is little difference in the accuracy of the times measured in hours and marks, and those measured in fifths of a night watch, despite the fact that a fifth of a night watch is approximately twice as long as a mark.

In both the solar and lunar eclipse times, there appears to be an improvement in accuracy in about AD 1090. This date coincides with the construction of Su Sung's clock tower in Pien. It would be naïve to attribute this improvement in timing accuracy directly to the construction of Su Sung's clock, indeed when the Sung were driven out of Pien in AD 1127 they clearly could not have used

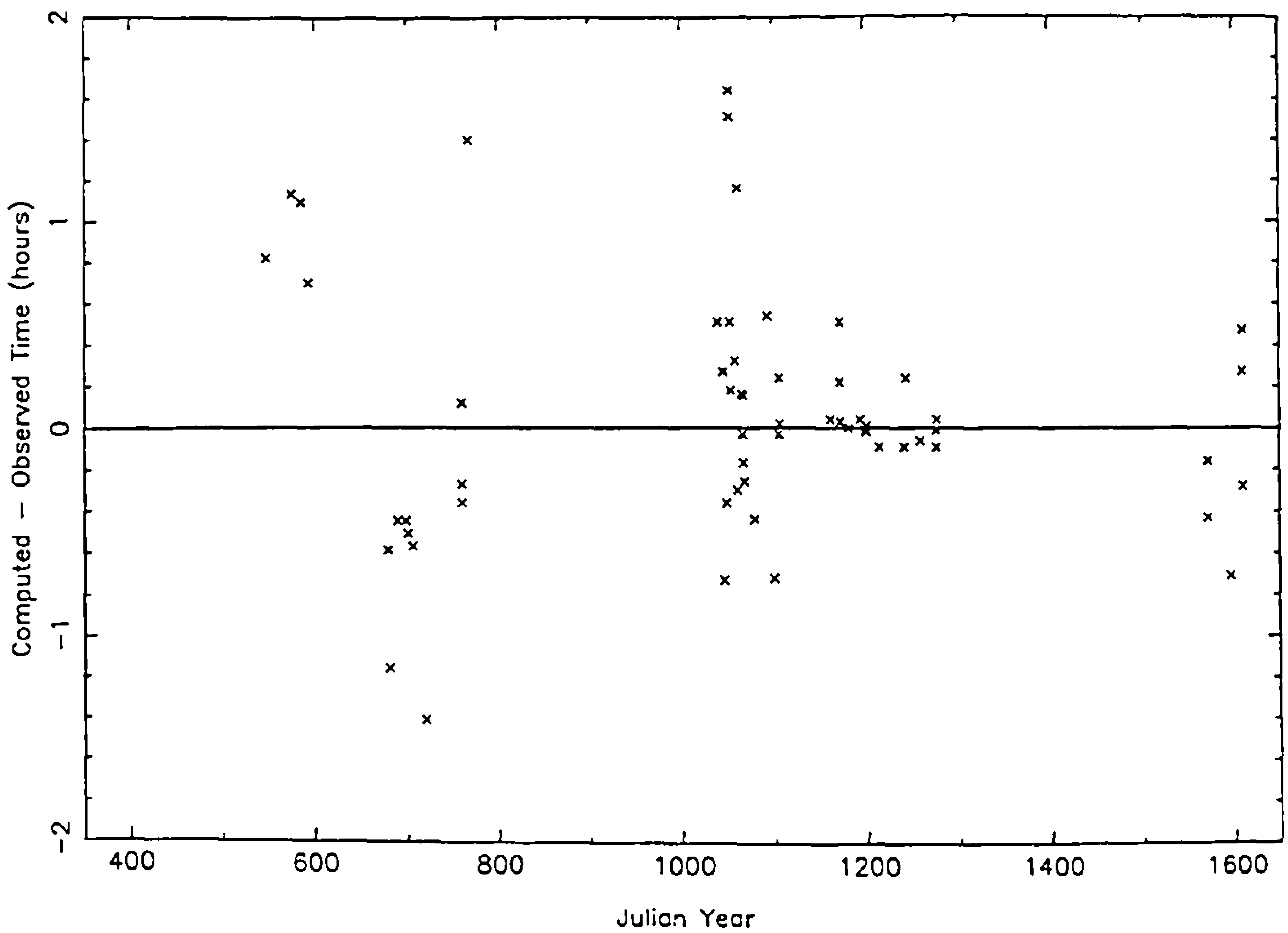


Figure 6.13: The error in the measured times of solar eclipses.

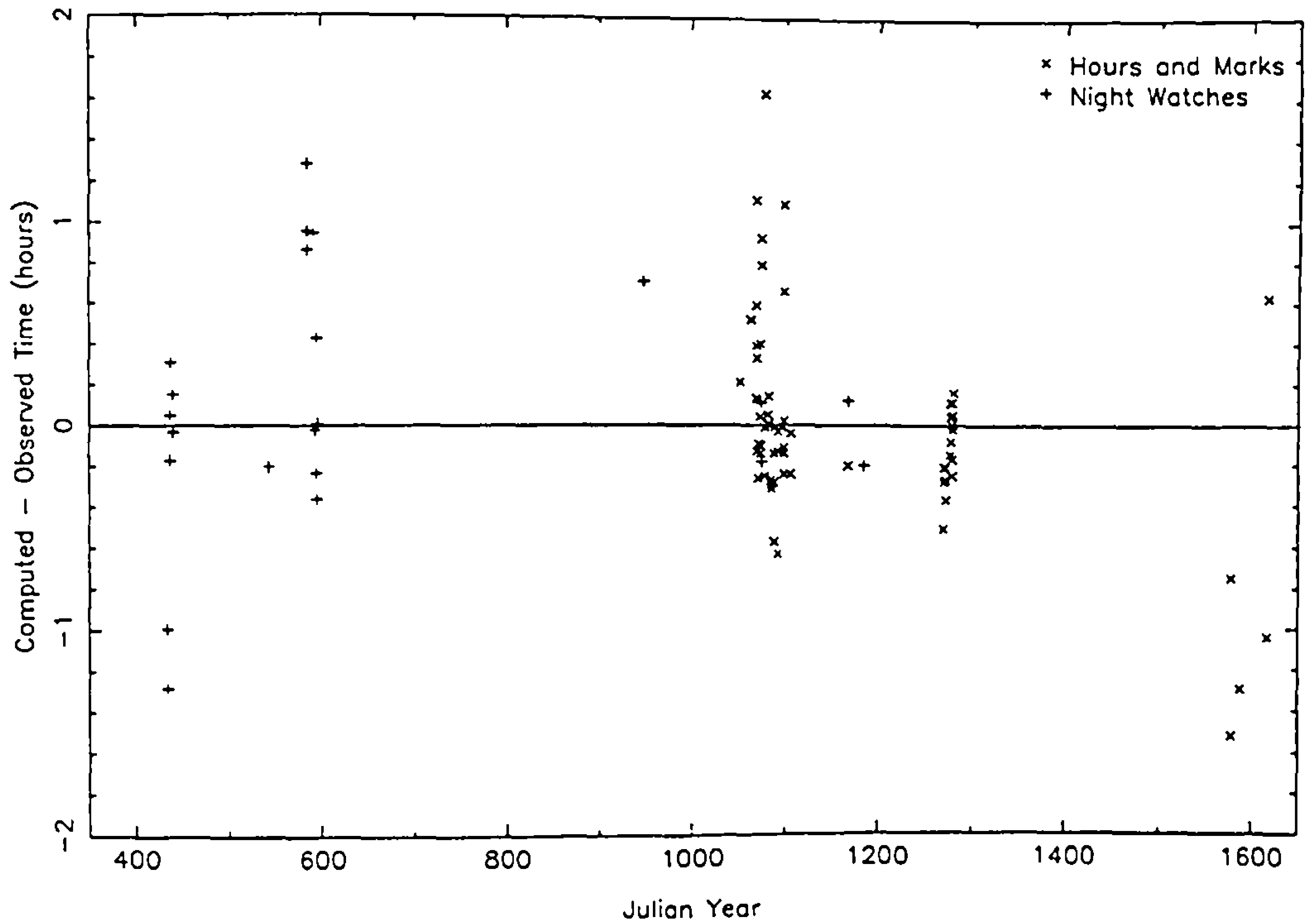


Figure 6.14: The error in the measured times of lunar eclipses.

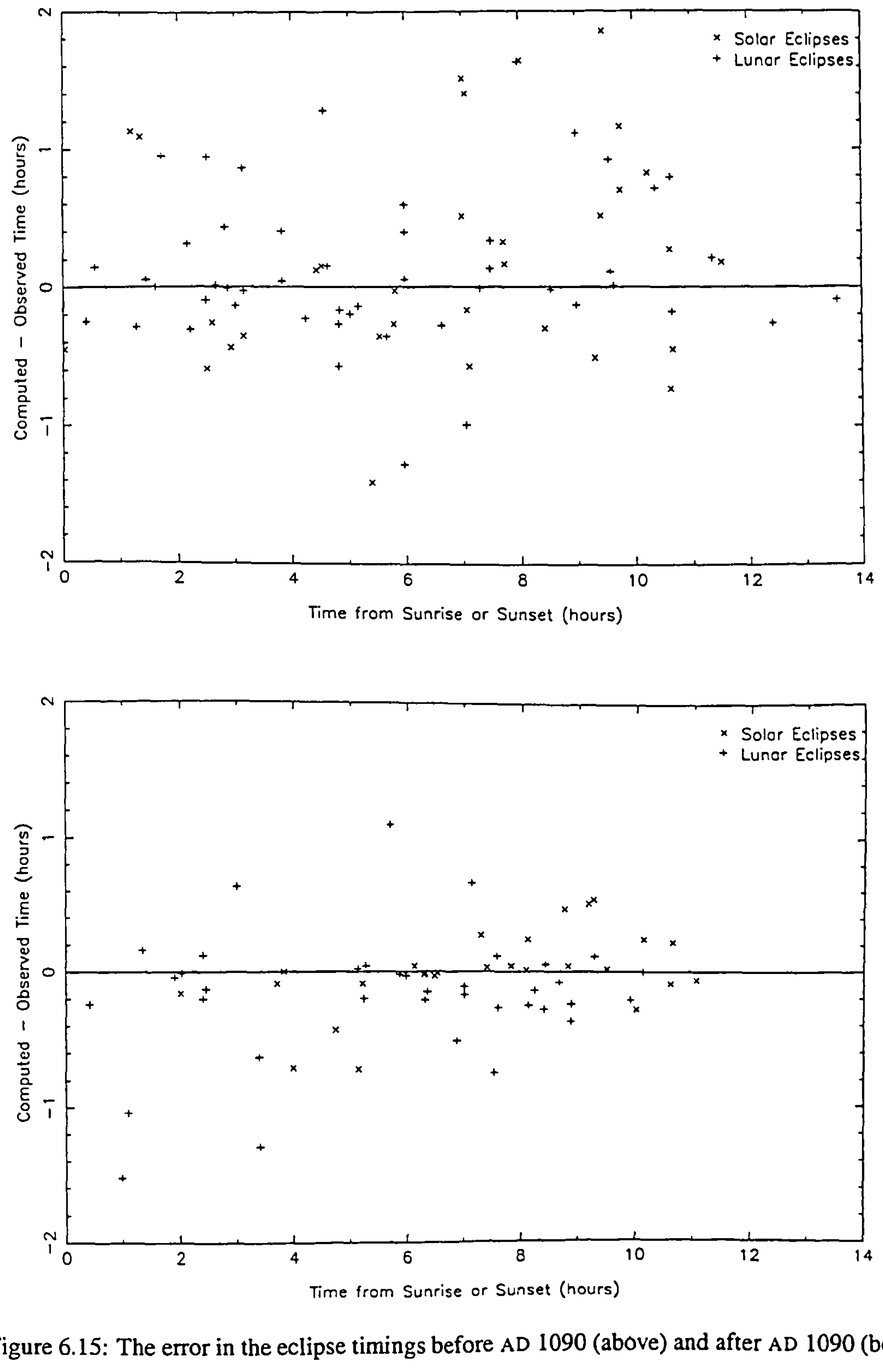


Figure 6.15: The error in the eclipse timings before AD 1090 (above) and after AD 1090 (below).

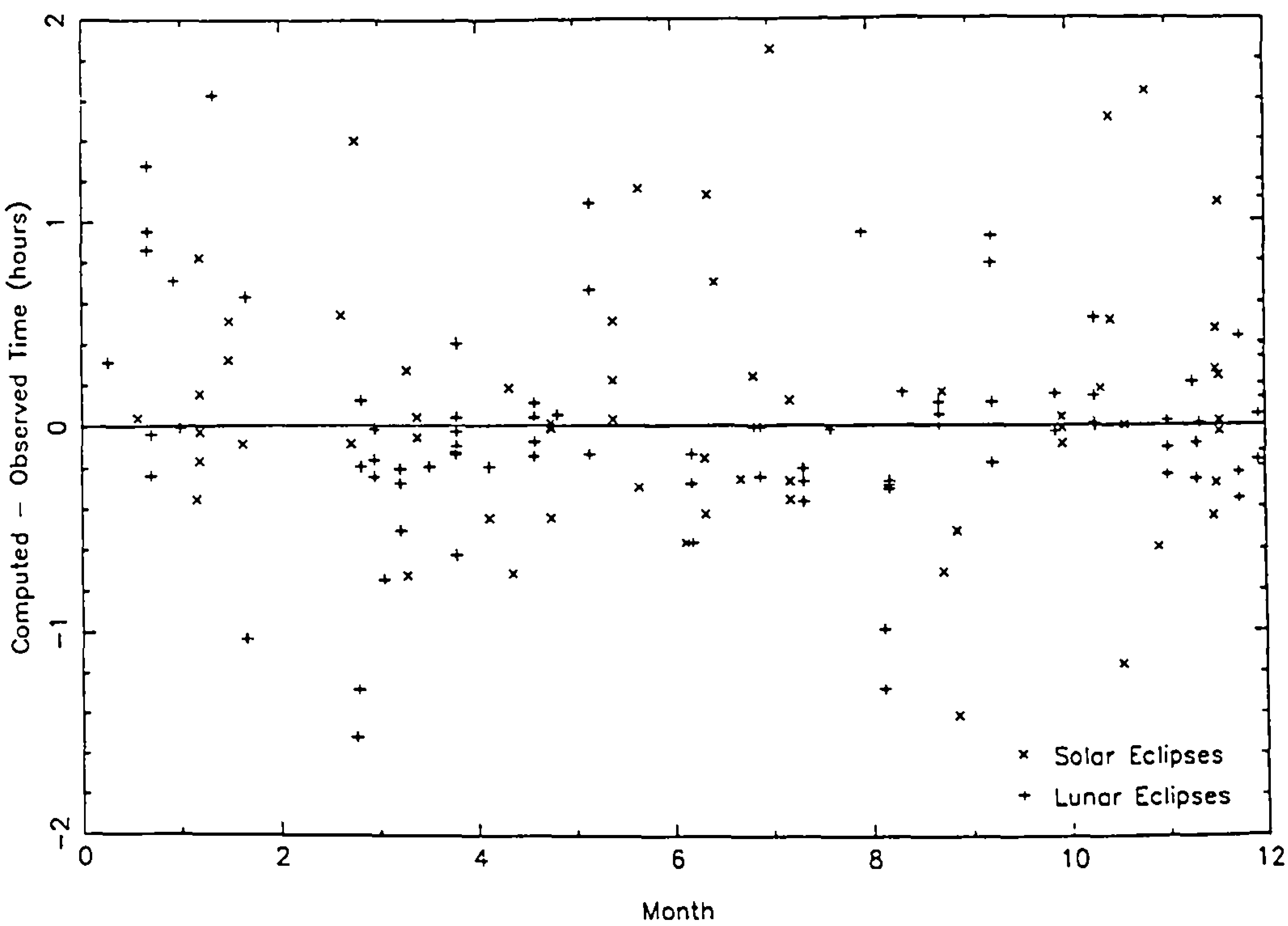


Figure 6.16: The error in the measured eclipse times throughout the year.

it in their observations, nevertheless it does suggest that there was a revolution in methods of time keeping, of which Su Sung's designs are at least an example, around this period. Towards the end of the Ming dynasty, however, the accuracy of the eclipse timings had decreased back to the levels seen five hundred years earlier. The level of accuracy achieved by the Sung and Yuan astronomers was not bettered until the middle of the eighteenth century when the Jesuit astronomers constructed new instruments for timing eclipses (Stephenson & Fatoohi 1995; Fatoohi & Stephenson 1996).

In Figure 6.15, the error in the measured times of the eclipse contacts is shown as a function of the interval between the eclipse and either sunrise (for solar eclipses) or sunset (for lunar eclipses). The data are split into two subsets — eclipses before AD 1090 and eclipses after AD 1090. This is the date at which an improvement in the accuracy of the timings was noted. It appears that in the first case there may be a slight increase in the dispersion of the error as the interval from sunrise or sunset increases. This suggests that the clocks used by the early Chinese astronomers were regulated every morning and evening. However, after AD 1090 this is not the case, suggesting that regulation every sunrise and sunset, whether it was performed or not, was not needed.

Finally, Figure 6.16 shows the error in the measured eclipse times as a function of the month of the year. It might be expected that there would be greater errors in the timing of eclipses in the winter months than in the summer, due, for example, to the effects of the change in temperature upon the viscosity of the water in the water clocks. However, as is clear from Figure 6.16, this is not the case. Evidently the Chinese astronomers were successful in their attempts to regulate the flow of water throughout the year.

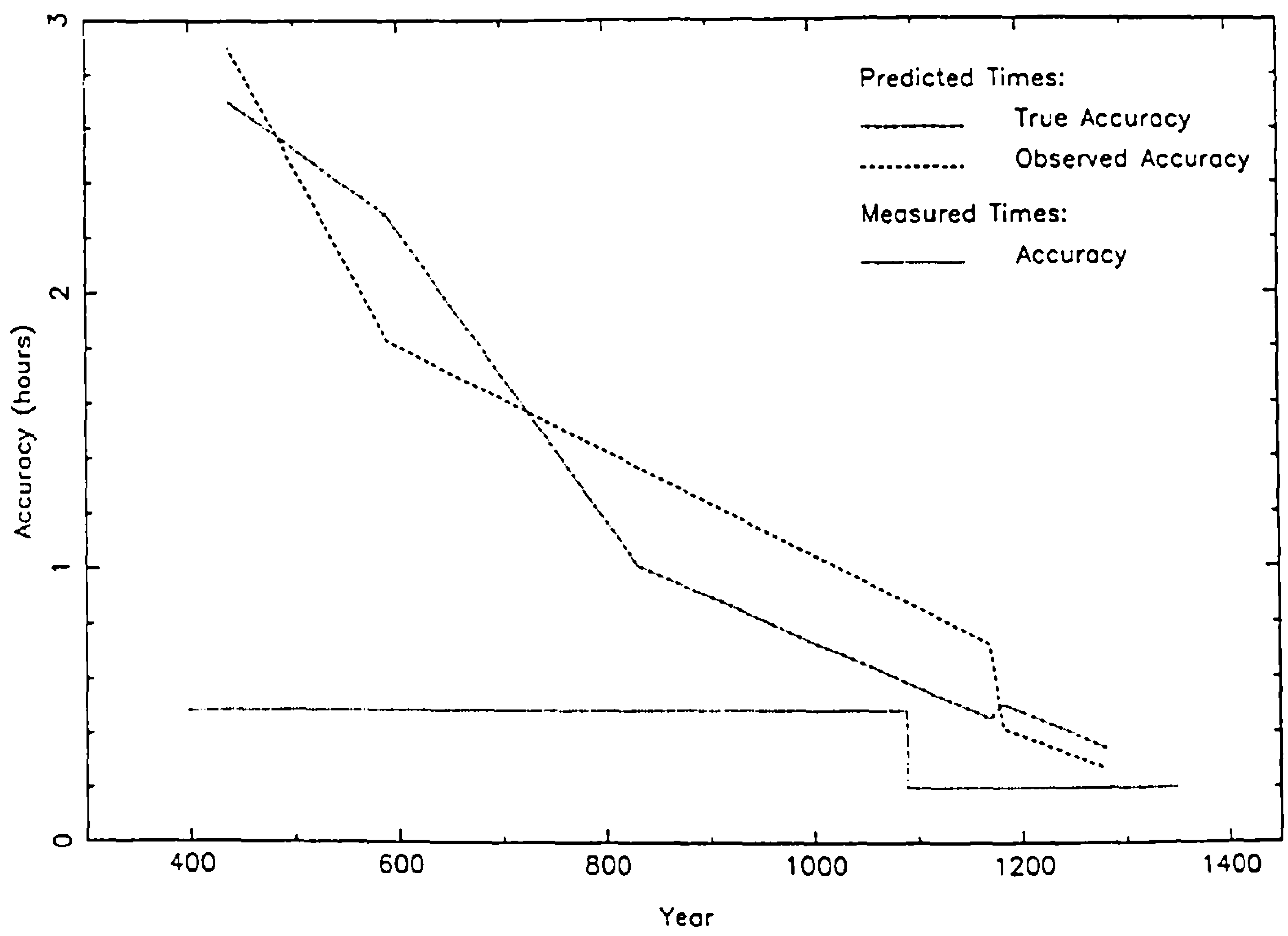


Figure 6.17: Schematic representation of the accuracy of the prediction of eclipse times.

6.9 Accuracy of the Predicted Times

It is possible to trace a great improvement in the ability to predict the time of an eclipse down through Chinese history. The *Ching-ch'u-li* system used by the Liu-Sung astronomers could only crudely predict the time of an eclipse to an observed accuracy of about 2.9 hours and a true accuracy of about 2.7 hours. By the Sui dynasty, the *K'ai-huang-li* was being used to make predictions to an observed accuracy of about 1.8 hours and a true accuracy of about 2.3 hours. Five hundred years later, the Sung astronomers of the middle of the twelfth century AD were predicting eclipses with an observed accuracy of about 0.7 hours and a true accuracy of about 0.5 hours. By the end of that century, the *Ta-ming-li* was able to predict eclipses with an observed accuracy of about 0.4 hours, and a true accuracy of about 0.5 hours. The Yuan dynasty *Shou-shih-li* calendar achieved even higher levels of accuracy than this, with both an observed and a true accuracy of about 0.3 hours.

It is unfortunate that there are no records of eclipse predictions made with the many calendar systems of the T'ang dynasty. One of the most important calendars of this period was the *Ta-yen-li*, compiled by I Hsing in AD 727. This calendar is discussed in chapter 27b of the *Hsin T'ang-shu*, where it is stated that it has been tested against a number of solar and lunar eclipses. However, no details of these tests are given, and so it is not possible to assess the accuracy of any eclipse predictions made with this calendar. Another important calendar from the T'ang dynasty is the *Hsuan-ming-li*. Again, no eclipse predictions made with this calendar are preserved in Chinese history. However, this calendar was used in Japan from the middle of the ninth until the end of the seventeenth century AD, and over one hundred eclipse predictions made with it are recorded in various Japanese sources. As I shall show in Chapter 7, the true accuracy of this calendar in predicting eclipses can be deduced to be about 1.0 hours.

Figure 6.17 shows schematically the improvement in the accuracy of the Chinese calendar systems to predict the time of eclipses. For each set of predictions the mean accuracy has been plotted against the approximate year that they were made. The points have been connected with straight lines to illustrate the improvement in accuracy over the period. However, these lines must not be taken to imply a linear improvement in the techniques used between two points, but are simply a way of indicating the general development down the centuries. Also shown in Figure 6.17 is the typical accuracy with which the times of eclipses were observed over the same period.

It is interesting to contrast the gradual, but steady, improvement in the ability of the Chinese astronomers to predict the time of an eclipse, with the complete lack of progress in their ability to measure the time of an eclipse before the end of the eleventh century AD, when there was a sudden improvement by a factor of more than 2 in the accuracy of the measured times. Furthermore, this occurred at around the time when the accuracy of the predictions was reaching about the same level as the observations. Indeed without this improvement in the ability to accurately measure the time of an eclipse, it is doubtful whether the improvements in the *Shou-shih-li* could have been formulated. Only when the accuracy of observation was higher than that of prediction could uncertainties in the predictions be reliably identified.

Chapter 7

Japan (c. AD 800 – 1600)

Ask, who is wise? — you'll find the self-same man
A sage in France, a madman in Japan;
And here some head beneath a mitre swells,
Which there had tingled to a cap and bells.
— Thomas Moore, *The Sceptic*, 1809, lines 17–20

7.1 Introduction

The history of Japan emerges from the legendary period around the sixth century AD. The *Nihongi*, or *Nihon shoki*, a chronicle written in about AD 720, recounts the history of Japan from the time of the gods down to AD 679. However, at least before the fifth century AD, it is clear that much of this history is fictitious, albeit a fiction that is probably based upon fact.[1] From archaeological evidence it seems that even as late as the third century BC, Japan was still in the stone age (Sugimoto & Swain 1978: 2). Chinese culture began to enter Japan from Korea around this time, and by the third century AD, local rule had been established in parts of the country (Tuge 1968). One of these small village states, the Yamato, began to grow in power and by around AD 350 had subdued the others to form Japan's first unified state (Sugimoto & Swain 1978: 3).

Over the next three centuries, Japan began to form links with its Korean and Chinese neighbours. Envoys and tributes were sent to the Chinese court and, more often, the Paekche state of Korea. During this period, the Japanese were profoundly influenced by Chinese culture, perhaps most significantly by the adoption at the start of the fifth century AD of the Chinese characters for writing. In AD 646, the Japanese clans were federated under an emperor, and a bureaucratic state, based upon that of T'ang China, was established. One result of this was that the Japanese began to imitate the Chinese practices in astronomy as well as other fields (Ronan 1996). In AD 628, the Japanese adopted the Chinese system of timekeeping and a water clock was constructed. By AD 675, the first astronomical observatory had been set up, and in AD 702, the Taiho civil code was promulgated. For the first time, this code set up regulations governing the administration and teaching of astrology and calendar making (Nakayama 1969: 10).

During the eighth century AD, the imperial family and the court nobles began to accumulate a vast wealth, and consequently significant power. Because of this they began to monopolize the governmental positions, with the result that they effectively became hereditary. The nobility began

[1]As Aston (1972: xv-xvi), who has translated the *Nihongi*, has written, "The earlier part furnishes a very complete assortment of all the forms of Untrue of which the human mind is capable, whether myth, legend, fable, romance, gossip, mere blundering, or downright fiction ... Then we have a series of legendary stories full of miraculous incidents, but in which grains of truth may here and there be discerned ... The narrative becomes more and more real as it goes on, until about the 5th century (AD) we find ourselves in what, without too violent a departure from truth, may be called genuine history..."

to turn away from Chinese culture, and with the abandonment of the practice of sending missions to the T'ang court in AD 894, official Chinese-Japanese relations were effectively cut (Sugimoto & Swain 1978: 28). It was not until the fifteenth century AD that Japan again began to experience any significant foreign influences on its society.

In this chapter I shall, after giving some necessary background on calendrical astronomy in Japan, examine the numerous reports of eclipse predictions made using the Chinese *Hsuan-ming-li* calendar system recorded in Chinese history. Not only does this allow the accuracy with which the Japanese astronomers were able to predict eclipses to be assessed, but it also provides a convenient method of determining the accuracy of the Chinese *Hsuan-ming-li* in predicting eclipses, without having to recalculate predictions using the description of the calendar in the *Hsin T'ang-shu*. As I have noted in Chapter 6 above, there are no eclipse predictions made with this calendar preserved in Chinese history, and so the Japanese records are of great value in tracing the development of the Chinese calendar at this period. Much of the following discussion is drawn from my article, Steele (1998c)

7.2 Calendrical Astronomy in Japan

The earliest reference to the calendar in Japanese history is in the 19th book of the *Nihongi*. The Emperor of Japan sent a mission to Paekche in AD 553 requesting, among other things, that "the men learned in medicine, divination, and in the calendar, have to take it in turn to come up (to the Japanese Court) ..."[2] The following year, Paekche responded to this request by sending, among others, Wang Po-son, an expert on the Chinese calendar. It is now generally believed that before this time, there was no native calendrical system in Japan, and that earlier dates given in the *Nihongi* were calculated retrospectively, and in some cases inaccurately, using Chinese systems (Nakayama, 1969: 7–8).

Over the next two centuries, Korea continued to supply Japan with the Chinese calendar. In AD 602, Paekche sent a priest to the Japanese Court to present books on calendar-making, astrology and geography (including geomancy), and to teach in these disciplines:

> "A Paekche priest named Kwal-leuk arrived and presented by way of tribute books of Calendar-making, of Astronomy, and of Geography, and also books of the art of invisibility and magic. At this time three or four pupils were selected, and made to study under Kwal-leuk. Ochin, the ancestor of the Yako no Fumibito, studied the art of Calendar-making. Koso, Otomo no Suguri, studied Astronomy and the art of invisibility. Hinamitatsu, Yamashiro no Omi, studied magic. They all studied so far as to perfect themselves in these arts."
>
> [*Nihongi*, 22, 7; trans. Aston (1972: II, 126)]

Following Ochin's study of the calendar, two years later the old calendar was repealed, and the *Yuan-chia-li* calendar was adopted (Wang 1988). Little more is known of the adoption of the Calendar in Japan at this early period. The situation is made confusing by a statement in the *Nihongi* that in AD 690 "in compliance with an Imperial order, the use of the *Yuan-chia* and the *I-feng*[3] calendars was begun."[4] At the start of the last century, Kozawa Masakata concluded that the *Yuan-chih-li* was used from AD 604 to AD 697, and the *I-feng-li* was used from AD 692 to AD 763 (Nakayama 1969: 70). Presumably both calendars were used simultaneously in the overlapping years.

In AD 735, the *Ta-yen-li* was brought to Japan. Unlike the earlier calendars which had come to Japan via Korea, the *Ta-yen-li* was brought directly from China by Kibi no Makibi. However, the calendar was not actually adopted in Japan until AD 764, by which time it had already been replaced in China. Similarly, the *Wu-chi-li* calendar was not adopted by the Japanese until AD 764, nearly eighty years after it had been brought from China (Nakayama 1969: 70). Finally, in AD 862, the

[2] *Nihongi*, 19, 38; trans. Aston (1972: II, 68)
[3] The *I-feng-li* was another name for the *Lin-te-li*, used in China between AD 665 and AD 728.
[4] *Nihongi*, 30, 19; trans. Aston (1972: II, 400).

Calendar	Date of Use in China	Date of Use in Japan
Yuan-chia-li	AD 445–509	c. AD 604–697
I-feng-li	AD 665–728	c. AD 692–763
Ta-yen-li	AD 726–762	AD 764–858
Wu-chih-li	AD 763–783	AD 858–862
Hsuan-ming-li	AD 822–892	AD 862–1685
Jokyo	-	AD 1685–

Table 7.1: Calendars adopted in ancient and medieval Japan.

Hsuan-ming-li was adopted. This calendar continued in use until AD 1685 when it was replaced by Japan's first indigenous calendar.

The long period without calendar reform in Japan may be attributed to a number of factors. In China, the calendar was often reformed when a new government came to power. However, in Japan there was an unbroken imperial line, and so there was no need for new calendars to be adopted to keep establishing the heavenly mandate to govern (Sugimoto & Swain 1978: 72). Furthermore, Japan's close links with China were cut towards the end of the ninth century when the country entered a state of semiseclusion. During this period, which lasted until the start of the fifteenth century, the Japanese were either unable, or unwilling, to adopt more recent Chinese calendar systems (Sugimoto & Swain 1978: 128). Finally, in Japan the practices of calendar-making and of divination were all part of the same *Yin-yang* office. Members of this office, like all of the Japanese government, were selected on a hereditary rather than a merit basis. By the tenth century AD, the *Yin-yang* office was divided into two factions — the calendrical officials of the Kamo clan, and the more important divinatory officials of the Abe clan (Wang 1988). Even when new calendars were proposed, because the Abe clan controlled the *Yin-yang* office, they were not put into use.

As the years past, the calendar gradually got less and less reliable. By the eleventh century AD, it even occasionally predicted eclipses a day earlier or later than they actually occurred. It should be noted, however, that this was not caused by an error in the calendar system as such, but by an error in the count of days. Such a situation occurred on the 18th October 1027 AD when an eclipse was observed a day earlier than had been expected:

> "9th month, 16th day, *kuei-ch'ou*. The Moon was eclipsed. Surprisingly, the calendar had not noted this, but rather (had predicted the eclipse) for the next day instead. This example was used in evidence by the instructors as by daytime they could not avoid reporting the eclipse. The Master Cheng-chou said that as this was a day-time eclipse it was not noted (correctly). The collator (of the records) wrote that the Moon was completely eclipsed. The loss should have begun at 3 marks, 30 *fen* in *wu*, as the (calculated time) of the middle of the eclipse was 2 marks, 8 *fen* in *wei*, and (the Moon) was returned to fullness at 1 mark, 2 *fen* in *yu*."
>
> [*Hsiao-yu-chi*]

It was not until AD 1685 that the *Hsuan-ming-li* was finally replaced by the *Jokyo* calendar. This was to be the first calendar to be compiled by a native astronomer, namely Yasui Harumi. It was based upon the methods of Kuo Shou-ching's *Shou-shih-li* as applied to Yasui Harumi's own observations. For a detailed discussion of the *Jokyo* calendar, see Nakayama (1969: 116–152).

Table 7.1 lists the calendars that were used in Japan up until AD 1685, together with the date of their use, both in Japan and in China. As we have seen, in many cases the calendar had ceased to be used in China before it was even adopted in Japan.

7.3 Timed Eclipse Records in Japanese History

The earliest astronomical records in Japanese history are from the seventh century AD. These are contained in the *Nihongi* and include observations of the eclipsed Sun or Moon, occultations of stars and planets, and the appearance of comets or meteors (Knobel 1905; Stephenson 1968). These astronomical observations in the *Nihongi* are of a similar style to those contained in the annals of the emperors contained in the Chinese dynastic histories, that is they are reported in amongst other affairs of state in chronological order. For example, on the 10th April 628 AD the Sun was seen to be totally eclipsed:

> "Summer, 5th month. Flies gathered together in great numbers. They clustered together for ten rods, and floated away in the air across the Shinano pass with a sound like thunder. They reached as far east as the province of Kamitsuke, and then spontaneously dispersed. 36th year, Spring, 2nd month, 27th day. The Empress took to her sick bed. 3rd month, 2nd day. There was a total eclipse of the Sun. 6th day. The Empress's illness became very grave, and (death) was unmistakably near..."
>
> [*Nihongi*, 22, 40-41; trans. Aston (1972: II, 155)]

In common with all of the other observations in the *Nihongi*, this record is not very detailed. No times are ever recorded for any of the eclipse records in this work.

From the eighth century AD, many hundreds of astronomical records are preserved. Unlike China, where the dynastic histories contain the vast majority of astronomical reports, in Japan astronomical records are found in many works, ranging from privately and officially compiled histories, to diaries and temple records. Kanda (1935) has made a detailed search through these sources up to AD 1600 and collected all of the of the available astronomical records together, preserving the original language of the texts. From around the end of the ninth century AD, a large number of the records of observations of solar and lunar eclipses also contain details of the eclipse as calculated using the *Hsuan-ming-li*. These details usually include the expected times of the beginning, middle, and end of the eclipses, given in double hours, marks and *fen*. In the *Hsuan-ming-li*, there were 100 *fen* in 1 mark.

All of the timed eclipse records in Japanese history up to AD 1600 are translated in Appendix C. I give below an example of a lunar and solar eclipse record:

- 30 January 1097 AD

> "1st month, 15th day, *keng-tzu*, full moon. At dusk there was an eclipse of the Moon. It was a little more than $6\frac{1}{2}$ fifteenths (eclipsed). The loss should have begun at 2 marks and 10 *fen* in the hour of *hsu*, as the calculated time (of the middle of the eclipse) was at 4 marks and 10 *fen* in the hour of *hsu*, and (the Moon) should have been returned to fullness at 2 marks and 5 *fen* in the hour of *hai*. The Moon should have moved within *hsing*."
>
> [*Shen-yu-chi*]

- 21 February 1319 AD

> "2nd month, new moon, *ting-hai*. The previous night heavy rain fell and a great wind blew. At dawn the wind and rain stopped and the sky cleared. That day the Sun was $\frac{14}{15}$ eclipsed. The loss should have begun at 4 marks and 17 *fen* in the hour of *mao*, as the calculated time (of the middle of the eclipse) was at 4 marks and 22 *fen* in the hour of *ch'en*, and (the Sun) should have been returned to fullness at 4 marks and 27 *fen* in the hour of *ssu*, according to the honourable Doctors of Astronomy. Investigating at that time (it was seen that) the loss began during the hour of *ch'en* and it was returned to fullness during the hour of *wu*. The calendar give the eclipse as $\frac{14}{15}$, but there was only $\frac{7}{15}$ eclipsed."
>
> [*Hua-yuan Yuan-ch'en-chi*]

It should be noted at this point that in none of the records is the time when the eclipse was actually observed ever reported to better than the nearest double-hour. In the second example quoted above, the observed time is considerably later than the predicted time of the eclipse. Using the *Hsuan-ming-li*, it was calculated that the eclipse should begin at a local time of 6.00 hours, reach its maximum at 8.01 hours and end at 10.02 hours. It was observed, however, to begin sometime between 7.00 and 9.00 hours, and end between 11.00 and 13.00 hours. It is perhaps surprising that discrepancies such as these, which are common throughout the Japanese eclipse records, do not seem to have concerned the Japanese astronomers.

Tables 7.2 and 7.3 list, respectively, all of the lunar and solar eclipse times predicted by the Japanese astronomers before AD 1600. Also given are the contact times of the eclipses as deduced from modern computations. In AD 794, the Imperial Residence was transfered to Heian, later to be renamed Kyoto (latitude = 35.03, longitude = -135.75). Kyoto remained the capital until the second half of the nineteenth century AD when Tokyo, the present day capital, was established. Although an earlier observatory had been built at Asuka during the seventh century AD (Kuniji 1979), the Japanese astronomers who made the eclipse calculations with the *Hsuan-ming* calendar were probably based in Kyoto. Most of the other major Japanese settlements, for example Kamakura, were military rather than cultural centres. Accordingly, Kyoto has been taken as the place of observation when making modern computations of the circumstances of the eclipses.

Many of the eclipses predicted by the Japanese astronomers were not actually visible in Japan. Usually this was because the eclipse occurred when the luminary was below the horizon; that is a lunar eclipse was expected to occur during the hours of daylight, or a solar eclipse during the night. Nine of the lunar eclipses listed in Table 7.2 actually refer to occasions when the Moon just missed the Earth's umbral shadow and a large penumbral eclipse occurred instead. In these cases, no computed times are given in the table, and the eclipse has been omitted from further analysis. Five of the solar eclipse predictions listed in Table 7.3 relate to eclipses that would have passed completely to either the north or the south of Kyoto. In these cases, only the time of maximum phase, which corresponds to the moment when the eclipse made its closest approach to Kyoto, is given in the table.

7.4 Accuracy of the Predicted Times

As I have noted above, there is often a considerable difference between the time that the Japanese astronomers predicted that an eclipse should occur, and their rough timings of when it was actually seen. Figures 7.1 and 7.2 show the difference between the time of the eclipse contacts as predicted by the Japanese astronomers, and that given by modern computations, for the lunar and solar eclipses respectively. From these figures, it is clear that there is also a systematic error between the computed times and the times predicted by the Japanese astronomers. This mean (systematic) error is shown as the dotted line in the two figures. It is equal to +0.97 hours for the lunar eclipses and +1.05 hours for the solar eclipses. However, as there is a considerable scatter in both sets of data, the difference between the two systematic errors is not significant. All that may be said is that in each case there is a systematic error making the predicted times early by about one hour.

It is now natural to ask the cause of this systematic error in the eclipse times. The most plausible answer to this problem is in a failure of the Japanese astronomers to correct for the differing locations of China and Japan. As noted in Section 6.4 above, by the time of the *Hsuan-ming-li* it was known that the circumstances of eclipses vary depending on the location of the observer. However, the early attempts made to correct for this were very crude, being hindered as they were by the lack of the notion of a spherical Earth in Chinese cosmology. Today, we know that the effect of moving east is to make the local time of a simultaneous event later in the day by 1 hour for every 15 degrees of longitude.[5] Lunar eclipses are such events, and so as the longitude of Yang-cheng, the meridian of

[5]By a simultaneous event, I mean an event that is observed at the same moment of an absolute time scale, such as is

	Predicted Time (hours)			Computed Time (hours)		
Date	1st	M	4th	1st	M	4th
937 Aug 24	21.24	-	1.72	22.84	-	2.34
938 Feb 17	17.48	-	22.84	19.24	-	2.34
939 Jan 18	21.00	21.24	21.48	21.19	21.37	21.54
982 Mar 13	-	21.72	23.48	-	-	-
1023 Dec 29	-	3.48	5.72	-	5.00	6.89
1027 Oct 18	11.72	-	17.24	14.41	–	18.11
1028 Oct 6	17.72	18.68	19.72	19.92	20.78	21.63
1078 Jan 30	1.50	3.73	5.97	3.25	5.15	7.05
1080 Nov 29	1.96	-	5.48	5.16	-	8.11
1081 Nov 19	11.48	13.72	15.96	15.20	17.07	18.93
1092 Apr 24	21.25	23.50	1.74	22.66	0.43	2.20
1093 Apr 14	13.48	15.24	15.97	14.96	16.22	17.47
1097 Jan 30	19.50	19.96	21.49	19.68	20.77	21.85
1111 Oct 18	23.99	1.75	3.74	2.18	3.56	4.94
1118 Jun 5	19.28	21.04	21.98	20.83	22.47	0.11
1127 May 27	19.24	19.96	21.24	21.60	22.52	23.43
1133 Aug 17	21.74	-	1.01	0.59	-	2.51
1155 Jun 17	3.51	3.75	3.99	5.72	6.15	6.58
1161 Aug 7	1.13	3.74	6.28	2.50	4.46	6.41
1167 Apr 6	15.17	16.63	18.35	15.84	17.02	18.19
1169 Mar 15	3.50	4.68	5.72	4.25	5.58	6.91
1203 Apr 28	3.48	5.24	6.68	6.65	7.33	15.03
1203 Oct 22	13.24	14.68	15.24	15.03	16.21	17.39
1210 Dec 2	16.92	-	19.24	18.62	-	20.95
1212 Nov 10	22.71	0.23	1.56	0.53	1.99	3.44
1221 Nov 1	21.43	22.60	23.80	23.60	0.75	1.89
1222 Apr 27	15.09	17.53	20.06	15.78	17.63	19.47
1226 Feb 14	6.46	8.96	11.42	8.81	10.73	12.64
1231 May 17	2.68	-	3.24	-	-	-
1233 Mar 27	18.54	20.73	22.93	19.33	21.90	22.86
1240 May 7	0.41	2.83	5.31	22.91	0.72	2.52
1244 Feb 25	14.99	-	19.98	16.63	-	20.47
1245 Feb 13	17.41	19.03	20.34	18.01	19.34	20.68
1245 Aug 9	17.24	18.44	19.60	18.52	19.88	21.24
1283 Jul 11	15.72	17.72	19.48	17.06	18.86	20.66
1287 Apr 29	17.96	20.20	22.20	18.97	20.70	22.42
1294 Jun 9	19.72	21.72	23.72	20.07	21.68	23.28
1308 Sep 1	16.68	-	-	18.06	-	-
1339 Jan 26	12.89	14.27	15.63	18.86	20.32	21.78
1339 Jul 21	18.87	20.34	21.80	18.86	20.32	21.78
1340 Jun 10	0.10	0.33	0.57	-	-	-
1340 Dec 5	5.30	6.50	7.62	-	-	-
1345 Sep 12	18.11	20.53	22.96	20.27	22.12	23.96
1346 Mar 8	15.31	16.80	18.31	15.68	17.26	18.83
1346 Sep 1	23.48	1.29	3.10	0.28	1.92	3.56
1349 Jul 1	3.42	5.65	7.88	7.25	9.04	10.82
1355 Feb 27	14.46	15.59	16.75	15.31	16.3	17.29
1355 Aug 23	19.95	20.83	22.03	20.72	21.31	21.90
1356 Feb 17	4.20	6.44	8.68	6.49	8.23	9.97
1359 Jun 11	0.20	1.72	3.72	1.10	2.64	4.17
1359 Dec 5	14.20	16.68	19.96	14.63	16.45	18.27
1363 Mar 30	12.68	115.26	17.96	12.33	14.09	15.95
1364 Mar 18	23.12	0.76	2.37	23.77	1.32	2.94
1364 Sep 12	6.20	8.01	9.77	7.37	9.08	10.78
1367 Jan 16	1.74	4.23	6.73	2.81	4.71	6.60
1367 Jul 12	12.20	14.44	16.68	14.68	16.46	18.24
1374 Feb 27	14.47	16.62	18.82	14.96	16.70	18.44
1393 Feb 27	15.18	16.68	18.21	14.23	15.81	17.39
1397 Dec 4	5.41	5.62	5.87	-	-	-

Table 7.2: Lunar eclipse predictions made with the *Hsuan-ming-li* in Japan.

Date	Predicted Time (hours) 1st	M	4th	Computed Time (hours) 1st	M	4th
1401 Mar 30	8.20	-	8.68	-	-	-
1401 Sep 22	23.27	-	0.38	-	-	-
1404 Jul 22	22.36	23.72	1.04	23.18	0.68	2.18
1407 May 22	5.03	-	-	8.42	-	-
1411 Sep 2	-	2.48	3.06	-	1.85	3.57
1423 Jan 26	5.19	5.49	5.75	-	-	-
1428 Sep 23	1.57	-	5.57	0.93	-	4.42
1432 Jun 13	17.00	19.58	0.00	19.02	20.89	22.76
1438 Mar 12	3.72	-	-	5.58	-	-
1464 Oct 15	16.68	19.08	21.37	16.44	18.10	19.79
1478 Jan 18	0.79	1.72	2.35	2.02	2.34	2.66
1484 Oct 4	21.33	21.87	22.45	23.17	0.01	0.85
1485 Mar 1	22.14	23.17	0.27	-	-	-
1526 Jun 24	17.49	-	21.96	19.88	-	23.41

Table 7.2 (cont.): Lunar eclipse predictions made with the *Hsuan-ming-li* in Japan.

Date	Predicted Time (hours) 1st	M	4th	Computed Time (hours) 1st	M	4th
875 Dec 2	-	1.72	-	-	4.10	-
877 May 17	-	1.24	-	-	3.36	-
975 Aug 10	5.25	7.48	9.00	6.83	7.89	9.55
982 Mar 28	7.72	9.24	9.73	9.29	10.16	11.07
1021 Aug 11	9.96	11.48	-	12.88	14.25	-
1029 Sep 11	5.25	7.24	9.24	6.72	7.71	8.80
1080 Dec 14	9.24	9.98	11.74	10.54	12.43	14.22
1085 Feb 27	3.25	3.99	5.75	4.60	5.06	5.53
1100 May 11	8.02	9.51	11.00	10.60	11.24	11.90
1106 Dec 27	13.56	13.81	14.02	13.48	14.36	15.18
1118 May 22	15.72	17.24	17.72	18.99	19.81	20.58
1143 Jan 18	-	5.24	6.20	-	5.61	-
1147 Oct 26	15.99	17.73	19.48	20.03	20.91	21.73
1148 Apr 20	11.98	13.06	13.77	14.82	15.96	17.00
1149 Apr 10	3.48	5.24	7.24	5.31	6.10	6.94
1187 Sep 4	17.24	17.72	-	20.39	21.12	-
1203 May 13	3.48	4.92	-	4.55	5.13	-
1210 Dec 18	5.24	-	7.96	6.38	-	8.13
1230 May 14	12.92	13.24	13.72	-	3.05	-
1245 Jul 25	16.11	17.38	19.24	16.27	17.43	18.47
1246 Jan 19	14.44	-	16.20	16.91	-	18.57
1267 May 25	15.72	-	-	18.57	-	-
1304 Nov 28	4.92	6.20	7.72	6.63	7.61	8.69
1307 Apr 3	16.34	18.16	20.01	-	20.31	-
1319 Feb 21	6.00	8.01	10.02	8.12	9.52	11.05
1346 Feb 22	11.49	13.02	14.53	13.26	14.44	15.52
1361 May 5	15.41	17.01	18.55	18.65	19.47	20.24
1374 Mar 14	8.01	8.39	8.81	5.54	8.60	9.40
1383 Aug 29	7.72	-	8.68	7.71	-	8.31
1397 May 27	4.87	8.68	8.47	6.70	7.70	8.81
1401 Mar 15	9.84	10.37	10.94	10.40	12.04	1.66
1484 Sep 20	9.03	11.12	13.48	7.67	8.99	10.45
1527 May 30	10.13	11.17	12.35	10.63	10.93	11.24

Table 7.3: Solar eclipse predictions made with the *Hsuan-ming-li* in Japan.

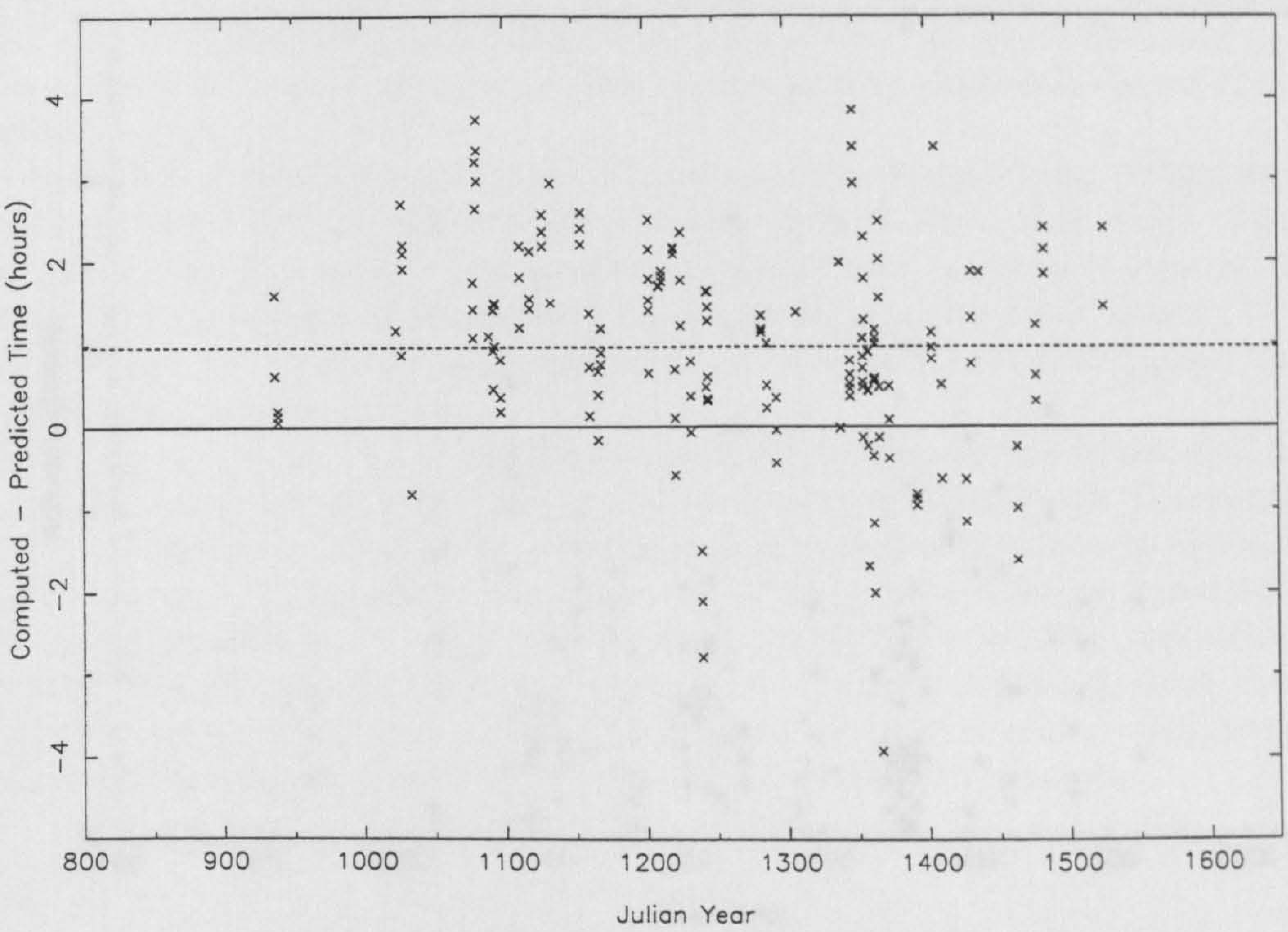


Figure 7.1: The error in the time of the lunar eclipse predictions made using the *Hsuan-ming-li*.

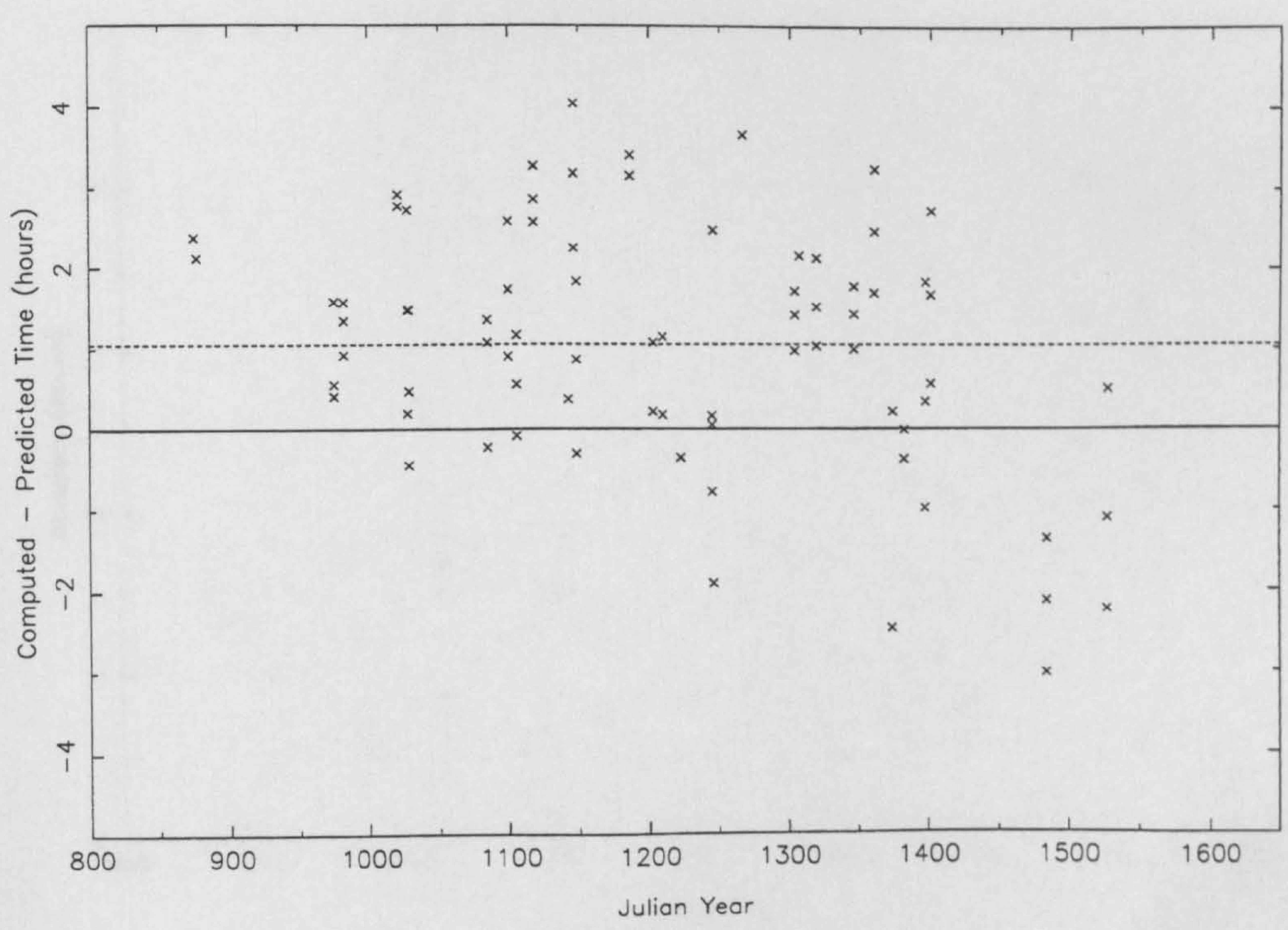


Figure 7.2: The error in the time of the solar eclipse predictions made using the *Hsuan-ming-li*.

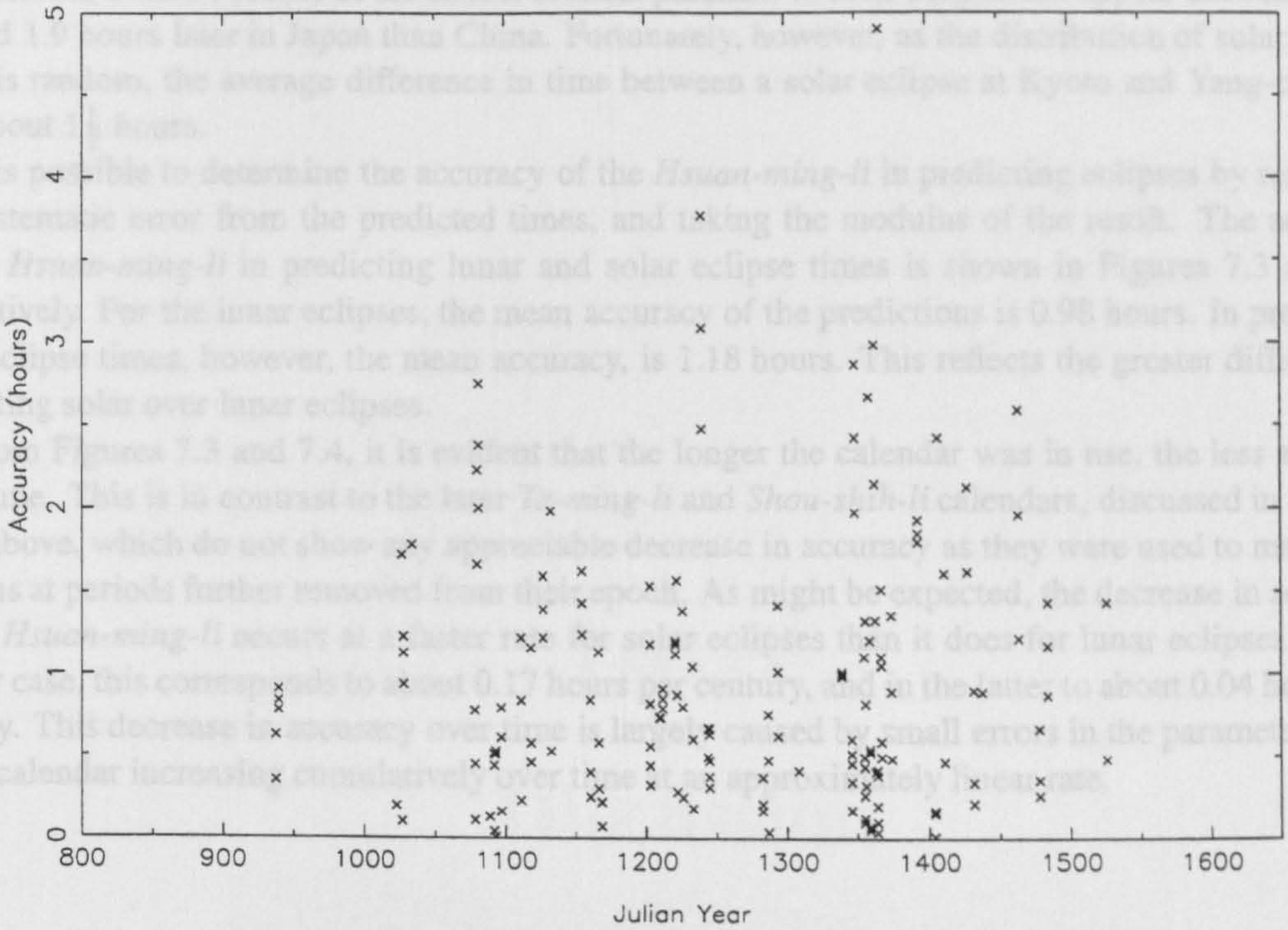


Figure 7.3: The accuracy of the *Hsuan-ming-li* in predicting the time of a lunar eclipse contact.

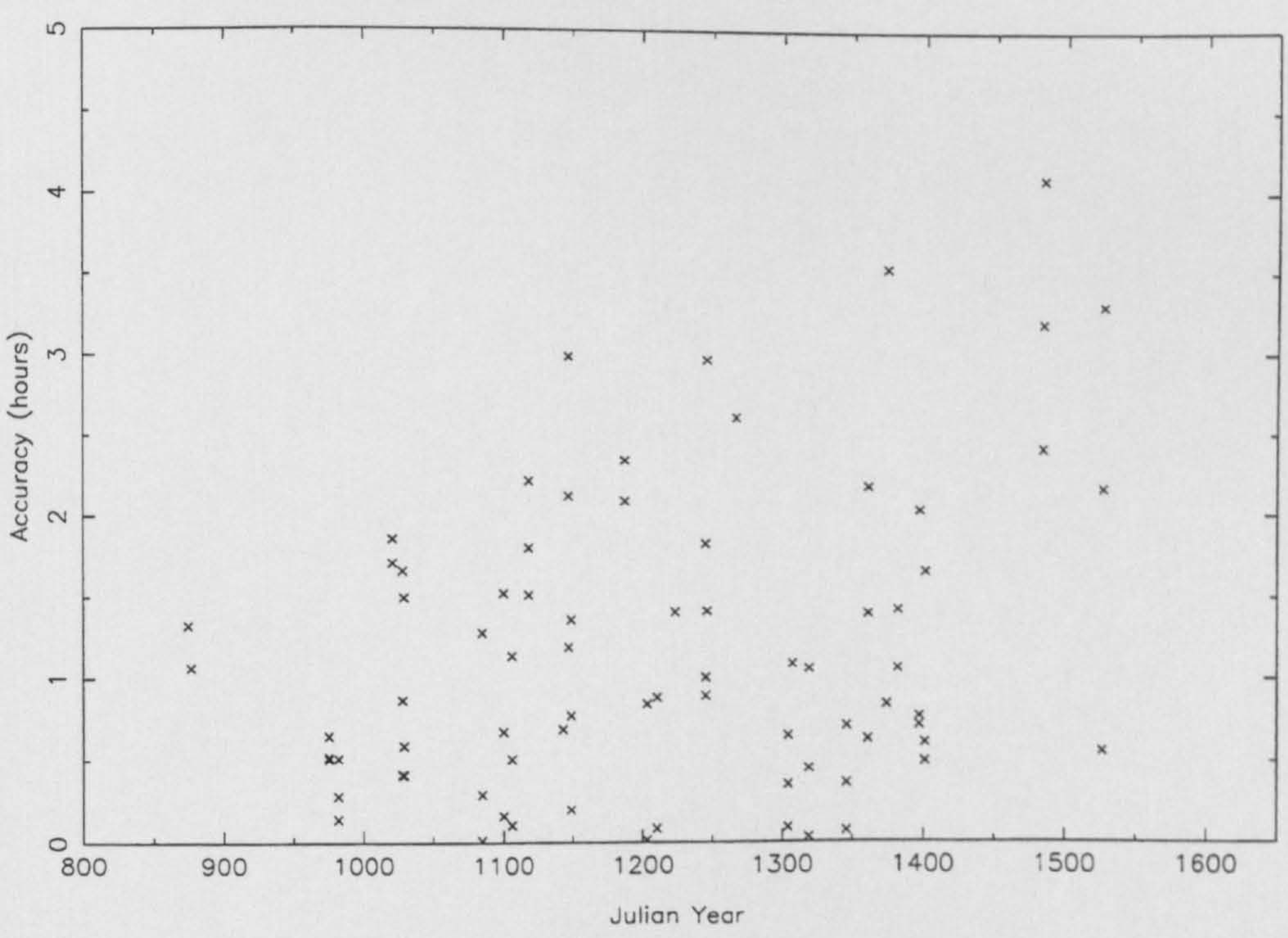


Figure 7.4: The accuracy of the *Hsuan-ming-li* in predicting the time of a solar eclipse contact.

the *Hsuan-ming-li*, is about 113° east, and that of Kyoto is about 136° east, the local time of a lunar eclipse in Kyoto is about $1\frac{1}{2}$ hours greater than that at Yang-cheng. Solar eclipses, however, are not simultaneous events because of the effects of lunar parallax. A solar eclipse can appear between about 1.1 and 1.9 hours later in Japan than China. Fortunately, however, as the distribution of solar eclipse times is random, the average difference in time between a solar eclipse at Kyoto and Yang-cheng is also about $1\frac{1}{2}$ hours.

It is possible to determine the accuracy of the *Hsuan-ming-li* in predicting eclipses by removing the systematic error from the predicted times, and taking the modulus of the result. The accuracy of the *Hsuan-ming-li* in predicting lunar and solar eclipse times is shown in Figures 7.3 and 7.4 respectively. For the lunar eclipses, the mean accuracy of the predictions is 0.98 hours. In predicting solar eclipse times, however, the mean accuracy, is 1.18 hours. This reflects the greater difficulty in predicting solar over lunar eclipses.

From Figures 7.3 and 7.4, it is evident that the longer the calendar was in use, the less accurate it became. This is in contrast to the later *Ta-ming-li* and *Shou-shih-li* calendars, discussed in Section 6.7.2 above, which do not show any appreciable decrease in accuracy as they were used to make predictions at periods further removed from their epoch. As might be expected, the decrease in accuracy of the *Hsuan-ming-li* occurs at a faster rate for solar eclipses than it does for lunar eclipses. In the former case, this corresponds to about 0.17 hours per century, and in the latter to about 0.04 hours per century. This decrease in accuracy over time is largely caused by small errors in the parameters used in the calendar increasing cumulatively over time at an approximately linear rate.

given by an atomic clock, no matter where they are observed from.

Part IV

Discussion

Chapter 8

Conclusion

Quickly, bring me a cup of wine, so that I may wet my mind and say something clever.
— Aristophanes

8.1 Historical Implications

In Chapters 2 to 7 of this work, I have discussed the eclipse records preserved in the history of each of the following cultures: Mesopotamia (principally Babylon), Ancient Europe, The Near East, and Later Medieval and Renaissance Europe, which form what I have termed the Western Heritage; and China and Japan, which form what I have termed the Eastern Heritage. In the present section I shall review the main findings of these chapters and their relevance to the history of astronomy. Some of the results of this work also have implications for present-day studies of the long-term changes in the Earth's rate of rotation. I shall discuss these in Section 8.2 below.

The main purpose of this work has been to collect together all known records of observations and predictions of eclipse times made by astronomers in the pre-telescopic period, and to obtain some understanding of the accuracy of these times. As I have shown in the preceding chapters, there exist marked differences between the methods used to time eclipses by astronomers in various cultures. For example, the Chinese astronomers seem to have used clepsydras almost exclusively in their observations, whereas the Islamic astronomers of the Near East determined the time by measuring the altitude of either the eclipsed luminary or a clock-star. Nevertheless, all of the astronomers seem to have been able to measure the time of an eclipse to within about half an hour, which is no small achievement.

Figure 8.1 shows schematically the typical accuracy of each set of timed eclipse observations. Clearly there is a general trend of improvement in accuracy down the centuries. This is shown by both the observations I have grouped into the Western Heritage, and those in the Eastern Heritage. The measurements made by the Babylonian, Greek and early Chinese astronomers were all made using fairly primitive clepsydras. It is unsurprising, therefore, that these are the least accurate of the observations. Much more accurate are the timings made by the Islamic astronomers of the Near East and the astronomers of Later Medieval and Renaissance Europe. These timings were made by either an altitude measurement or, occasionally during the Renaissance, a mechanical clock. However, it is interesting to note that, around the beginning of the twelfth century AD, the Chinese astronomers had developed water-powered clocks that were of comparable accuracy to the methods used in the west.

It would seem that the optimum accuracy in timing eclipses that could be achieved by astronomers in the pre-telescopic period was about 0.1 hours or 6 minutes. Indeed, even after the invention of the telescope at the start of the seventeenth century AD, European astronomers were not able to determine the time of eclipses significantly more accurately until after about AD 1650.

Figure 8.2 shows schematically the accuracy of the methods used to predict the time of an eclipse in the different cultures. It is interesting to contrast the lack of improvement in the accuracy of

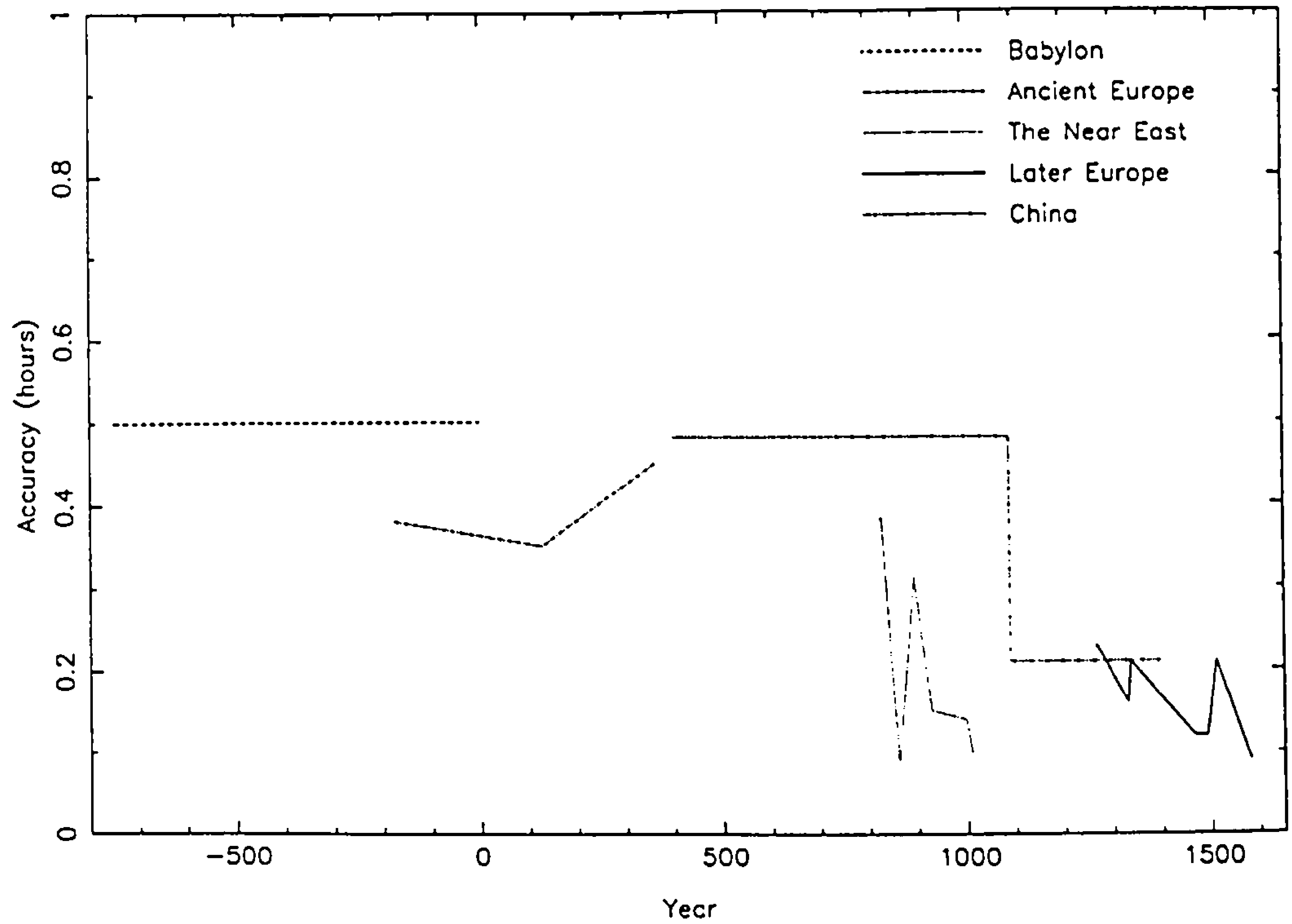


Figure 8.1: Schematic representation of the accuracy of observation of the time of an eclipse in different parts of the world.

the Babylonian predictions down the centuries with the definite trend of improvement shown by the Chinese predictions. By the end of the first millennium AD, the Chinese predictions had reached a comparable level of accuracy to those made in the Near East and Europe. Unfortunately, there are no records of Chinese eclipse predictions from after the thirteenth century AD. However, as the calendar system that was used for making these predictions remained essentially unchanged from AD 1280 to the time of the Jesuits (c. AD 1660), it would be expected that the accuracy of the predictions would remain at a more or less stable level over this period.

It is also noticeable that there was not necessarily a straightforward improvement in the accuracy of the predictions made by the astronomers of the Near East and Europe. The predictions made by al-Battānī are significantly less accurate than those made by his contemporaries; however, this is unsurprising since he used Ptolemy's tables for calculating his eclipses, rather than recently compiled tables as used by the other astronomers. Similarly, the predictions made by Regiomontanus and Walther in the fifteenth century AD are significantly less accurate than those made by earlier European astronomers. All of the European predictions, except those made by Levi ben Gerson, were made with the *Alfonsine Tables*. However, it is possible that *Alfonsine Tables* which circulated in the fourteenth century AD were not the same as those that had been available in the thirteenth century AD. Furthermore, it may be that the later astronomers used inaccurate meridians when making their calculations.

In addition to tracing the development of the accuracy of eclipse observation and prediction, a number of other important discoveries have been made and questions answered for the first time in the present study. These include:

- A tablet containing an observation of a total solar eclipse observed in Babylon has been dated to the 30th June 10 BC. This is the latest known Babylonian observation by some 14 years, and

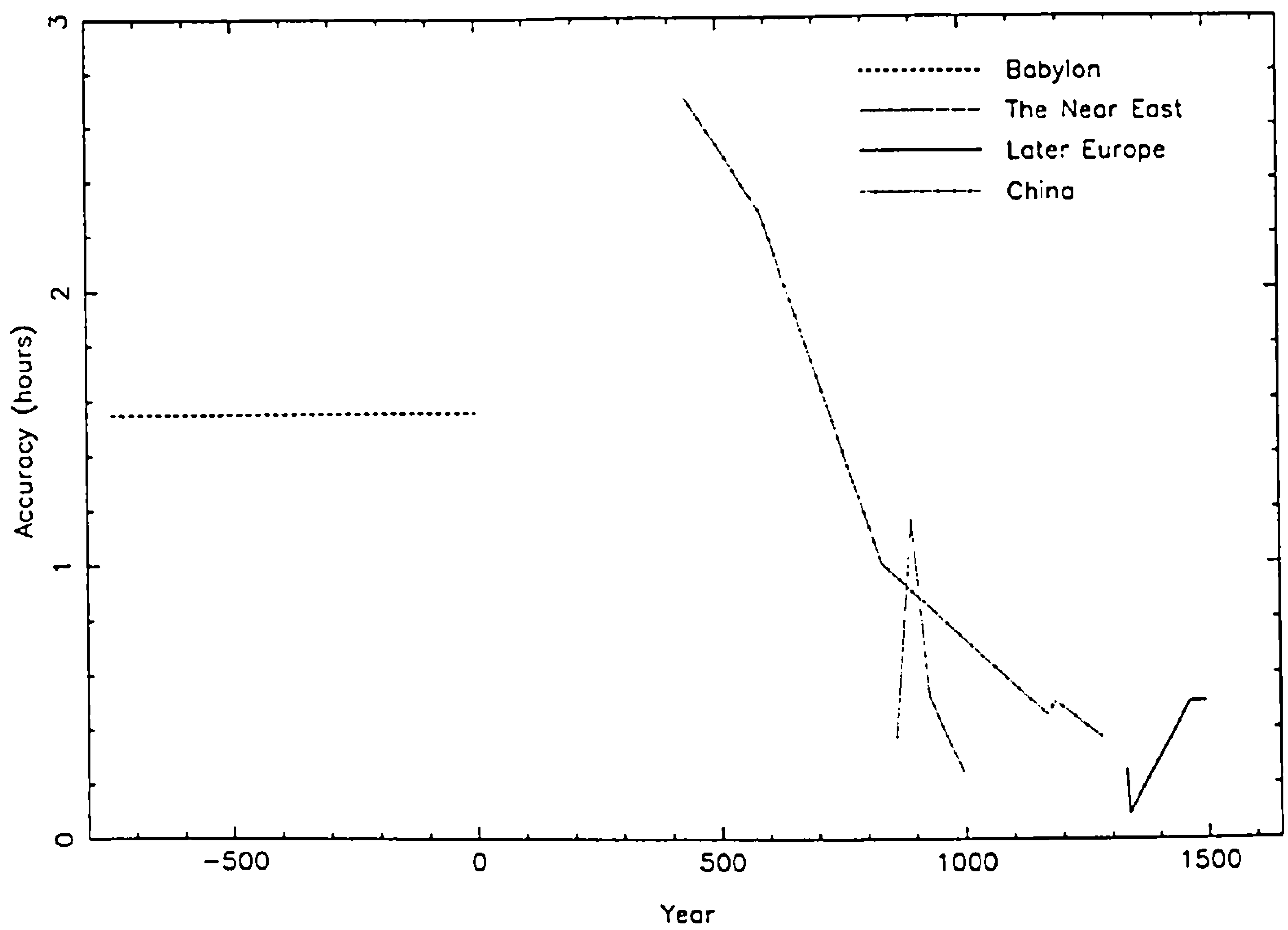


Figure 8.2: Schematic representation of the accuracy of prediction of the time of an eclipse in different parts of the world.

is only the second record of a total solar eclipse preserved in the cuneiform record.

- It has been shown that the Babylonian astronomers defined sunrise and sunset as the moment the upper limb of the Sun crossed the horizon. This is of great importance as all Babylonian times are quoted relative to one of these two moments.

- It has been shown that when the Babylonian astronomers predicted the time of an eclipse, this moment relates to the moment that the eclipse was expected to begin.[1] This is also an important discovery as it indicates that the predictions were not made using the schemes found in the Babylonian texts of mathematical astronomy, but rather with more primitive schemes which utilized the Saros cycle.

- The relationship between the various units of time used in China (in particular the mark and the double hour) has been fully explained. In particular it has been shown that the eighth "small" mark was always at the end of each double or single hour.

- It has been shown that all of the eclipse times preserved in Japanese history were in fact predicted using an out of date Chinese calendar system that made no allowance for the significant difference in longitude of the two countries.

8.2 Geophysical Implications

One important byproduct of the present study is that it provides useful information on the reliability of investigations into the long-term variations in the Earth's rate of rotation. Stephenson & Morrison

[1]In contrast to astronomers of other cultures who often predicted other contacts as well.

(1995) have recently made an extensive study of these changes in Earth's rotation based largely upon records of observations of historical eclipses. In contrast to earlier studies by Fotheringham (1920b) and others, Stephenson & Morrison (1995) have not only used observations of total solar eclipses, but also a large number of eclipse timings made by early astronomers. However, some authors, for example Cohen & Newton (1983) and Rochberg-Halton (1989b), have raised the question, "how do we know that these times were measured, and not predicted, by the early astronomers?" It is clear from the present study that the times were indeed measured for, in general, the preserved observed times are significantly more accurate than the times that are known to have been predicted. Furthermore, the nature of the errors of some of the observed times — such as the existence of random clock-drifts in the Babylonian timings — are characteristic of times that were indeed measured.

Another source of concern regarding the use of timed eclipse observations by Stephenson & Morrison (1995) is the small number of group of timings from China that give radically different times for the same eclipse in two sources. As I have shown in Section 6.7.3, however, this can be explained by the historical facts. At this time there were two observatories functioning in the Chinese capital, each perhaps using a different system of time measurement, and so it is not surprising that two different accounts of the same eclipse are preserved.

Finally, this study has uncovered a number of eclipse observations that were not available to Stephenson & Morrison (1995). Most of these, for example all of observations from Later Medieval and Renaissance Europe, were made at too recent an epoch to provide any significant information about the Earth's rotational clock error, ΔT. A small number of additional Babylonian eclipse timings have also been uncovered. However, these are too few in number to allow any refinement of the ΔT curve, although they do at least provide further support of its general trend. However, the observation of the solar eclipse on the 30th June 10 BC may be of some value.

Figure 8.3 shows the computed track of totality for this eclipse based upon the ΔT value given by the spline fit of Stephenson & Morrison (1995).[2] It can be seen that Babylon is on the southern limit of totality for this eclipse. Therefore, if it can be conclusively proved that this eclipse was total, then this observation will provide a critical limit to the value of ΔT at this period. Let me review the evidence in favour of totality:

1. The language used in the report of the observation is very dramatic in nature. This does not conclusively prove that the eclipse was total, but does suggest that the event was very noticeable.

2. During the eclipse, Sirius and three planets were stated to be visible. Once again this does not prove that the eclipse was total, but does indicate a very large eclipse.

3. The eclipse is described as reaching "the inside of the Sun". This strongly suggests that the whole of the Sun was covered.

4. After reaching the inside of the Sun, the length of time of maximum phase is recorded. A duration of maximum is only reported in one other Babylonian record of a solar eclipse — the total eclipse in 136 BC — and is never given for a partial solar eclipse. This strongly implies that the eclipse was total.

In the light of these comments, in particular points 3 and 4, it seems safe to conclude that the eclipse in 10 BC was in all likelihood seen to be total in Babylon.

The simple fact that the eclipse in 10 BC was observed to be total in Babylon precisely confines ΔT to the range 8630–10710 seconds at that date. This is illustrated in Figure 8.4. In this Figure, the vertical lines represent the ranges within which ΔT must lie at that date. In addition to the ΔT range

[2] This map was kindly prepared by Mrs. Pauline Russell and Prof. F. Richard Stephenson of the Department of Physics, University of Durham.

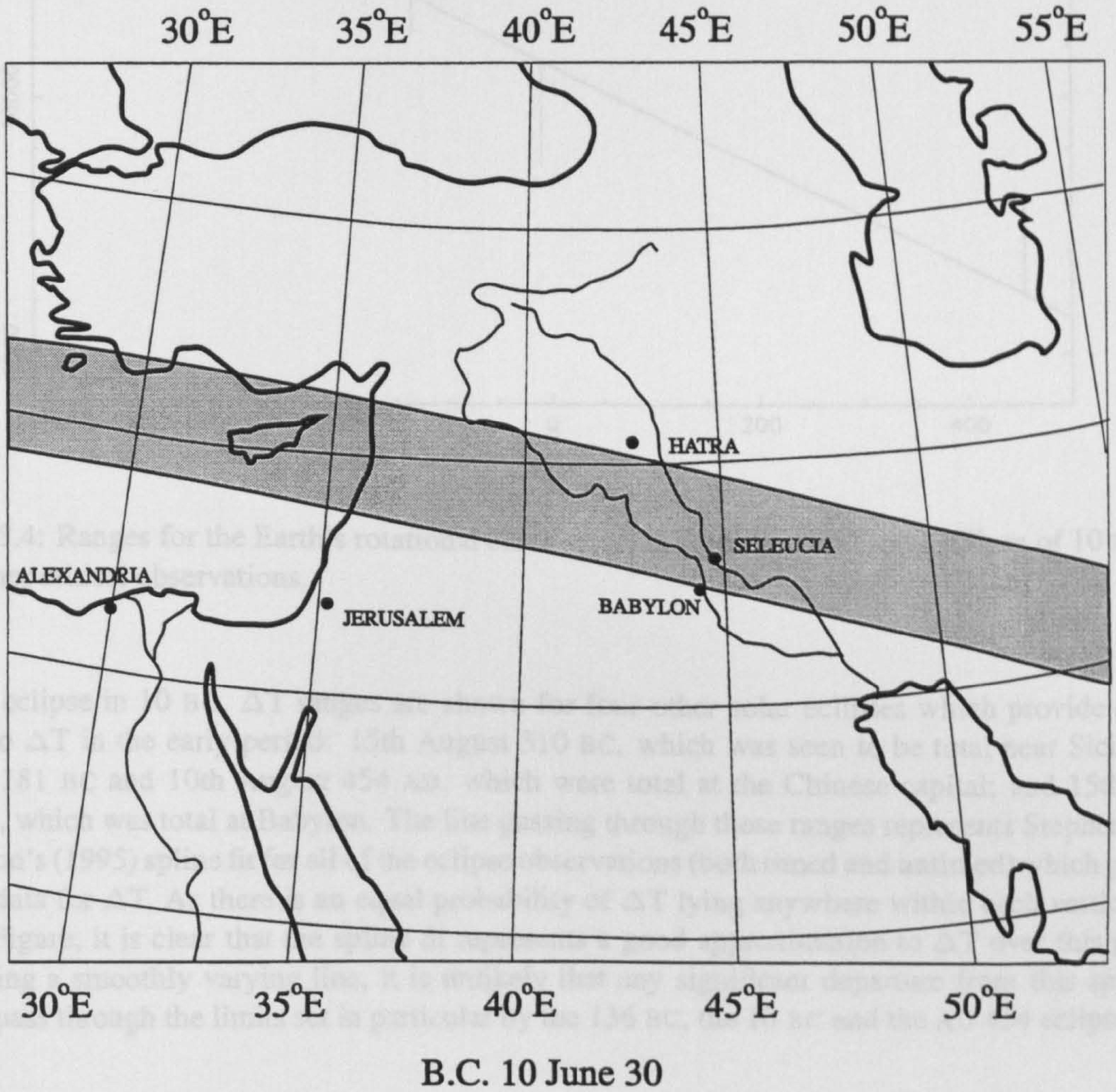


Figure 8.3: Track of totality for the solar eclipse on the 30th June 10 BC.

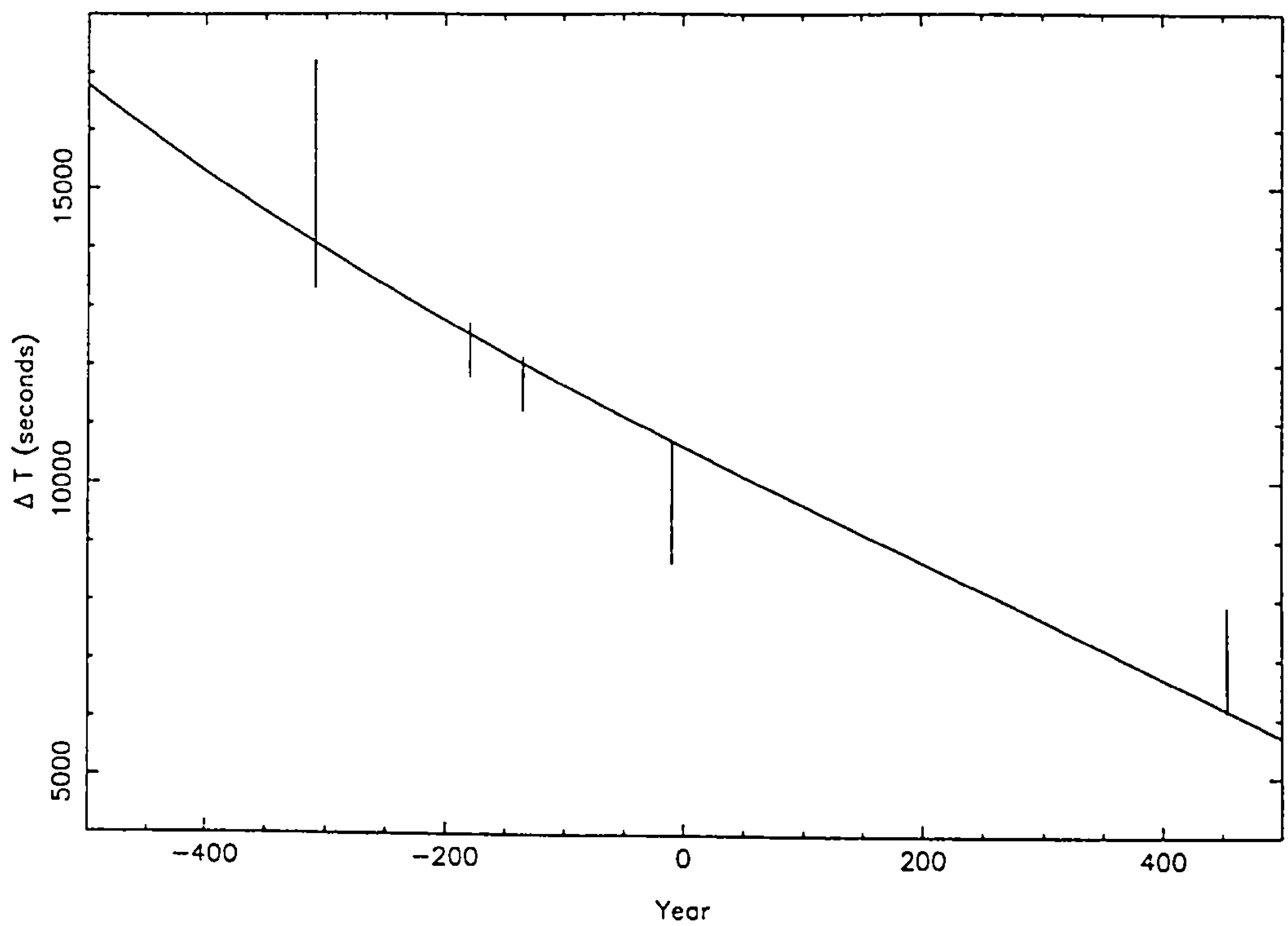


Figure 8.4: Ranges for the Earth's rotational clock error, ΔT, for the total solar eclipse of 10 BC and four other critical observations.

for the eclipse in 10 BC, ΔT ranges are shown for four other solar eclipses which provide critical limits to ΔT in the early period: 15th August 310 BC, which was seen to be total near Sicily; 4th March 181 BC and 10th August 454 AD, which were total at the Chinese capital; and 15th April 136 BC, which was total at Babylon. The line passing through these ranges represents Stephenson & Morrison's (1995) spline fit for all of the eclipse observations (both timed and untimed) which provide useful data for ΔT. As there is an equal probability of ΔT lying anywhere within each vertical line in the Figure, it is clear that the spline fit represents a good approximation to ΔT over this period. Assuming a smoothly varying line, it is unlikely that any significant departure from this spline fit would pass through the limits set in particular by the 136 BC, the 10 BC and the AD 454 eclipses.

8.3 Concluding Remarks

The present study has demonstrated some of the ways in which elements of history, linguistics and astronomy can be used together for their mutual benefit. By making use of modern computations of the circumstances of eclipses in the past it has been possible to gain a greater understanding of the ways in which eclipses were observed and predicted by early astronomers. Furthermore, by using modern computations of eclipses and planetary and stellar visibilities, a number of astronomical records have been dated. This is not only interesting in providing information regarding the dates of the individual records, but also in allowing a greater overview of the periods in which astronomers were active in various cultures. Finally, the study of early astronomical records is of reciprocal use in modern science by providing long-baseline data for investigations into the variations in the Earth's rate of rotation.

This study also enhances our knowledge of the interaction between observation and theory in early astronomy. Most previous studies made in the history of astronomy have concentrated on the various aspects of astronomical theory reported in antiquity without considering the actual records of observations and predictions made by the astronomers themselves. For example, although many studies have been made of Babylonian mathematical astronomy, it has not been until recently that the actual observational records have been investigated. They have revealed that some of the predictions found in these texts were made using different schemes from those claimed in the mathematical astronomical texts. Similarly, I have shown that the many predictions of eclipses contained in the Babylonian Astronomical Diaries were not made using the schemes found in the ACT type texts. Only by considering both types of astronomy, observational and theoretical, in tandem may we gain a full insight into historical astronomical practices.

Part V

Appendicies

Appendix A

Eclipse Records in the Late Babylonian Astronomical Texts

The following tables list the eclipses recorded in the Astronomical Diaries, the Goal-Year Texts, the Eclipse Texts, the Almanacs, and the Normal Star Almanacs. Within each of these categories, the tablets are listed in chronological order of their earliest eclipse report. For each tablet, the following details of each eclipse are given: the side, column (if appropriate), and line numbers of the report, the Julian date of the eclipse, whether the eclipse was observed or predicted, whether there are any times of the eclipse and its phases preserved ("Y" signifies that there is at least one fully preserved time, "D" signifies that there is only a partially preserved timing, and "N" signifies that there is no timing preserved), and any comments on the eclipse (for example, whether the eclipse is also reported on another tablet).

In compiling these lists, I have used the editions of the Astronomical Diaries by Sachs & Hunger (1988, 1989, 1996), and of the Eclipse Texts by Sachs & Hunger (1998). In addition, the reports on the solar eclipse text BM 36599 + 36941 + 36737 + 47919, have been taken from Aaboe & Sachs (1969), and those on BM 71537 have been taken from a transliteration of the tablet kindly supplied by Dr. C. B. F. Walker. The eclipse records in the Goal-Year Texts have been taken from Huber (1973), except for those on LBAT 1251 + 1252 which has been published by Hunger (1998). The eclipse records in the Almanacs and Normal Star Almanacs have been taken from a number of sources: LBAT 1174 has been published by Hunger (1998), LBAT 1195 and LBAT 1193 by Sachs & Walker (1984), DT 143 by Sachs (1976), and MN 86.11.369 by Walker & Roughton (1998); the other solar eclipses have kindly been provided by Prof. N. A. Roughton from his unpublished translations; and the remaining lunar eclipses have been read from the copies of the original tablets drawn by T. G. Pinches and J. N. Strassmaier and published by Sachs (1955).

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
BM 32315	II, 1 III, 4'	-651 Jul 2 -651 Dec 27	P P	N N	
VAT 4956	Obv. 17	-567 Jul 4	P	N	
LBAT 166	Obv. 16'	-382 Jun 29	P	N	
LBAT 181	Rev. 8'–10'	-370 Nov 11	O	Y	cf. LBAT *1414 (Eclipse Text)
LBAT *218	Obv. 6'–8'	-366 Mar 6	O	Y	
BM 35184	III, 5–6	-366 Aug 30	O	N	
BM 36913	Obv. 5'	-356 Feb 14	P	Y	
LBAT *189	Obv. 20–23	-345 Jan 14	O	Y	
BM 37231	Obv. 7'–8'	-333 May 29	O	D	
BM 36761 + 36390	Obv. 3'	-330 Sep 20	O	D	
BM 34794 + 34919 + 34990 + 35071 + 35329	Obv. 5'	-324 May 18	P	N	
LBAT 212 + 213	Obv. 9'	-321 Apr 17	P	N	
LBAT 217	Obv. 5'	-307 Jul 9	O	Y	
BM 34616 + 45901	Obv. 18' Rev. 17'	-302 Sep 12 -301 Mar 7	P ?	N N	
BM 32272 + 32288 + 32422 + 32501 + 32624	17	-291 Aug 11	P	Y	
LBAT *228	Obv. 9'–10'	-286 May 20	O	N	
LBAT 232	Rev. 5	-280 Jan 16	P	N	
BM 36710 + 92688 + 92689	Rev. 6'–8'	-272 Feb 16	O	Y	
LBAT 267	Obv. 3'	-248 Apr 19	P	Y	cf. LBAT **1216 (Goal-year Text)
BM 45949	Obv. 3–4	-247 Oct 3	O	N	
BM 32889 + 32967 + 41614 + 41618	Rev. 11'	-246 Sep 22	P	Y	
BM 55511		-238 Apr 28	O	Y	
LBAT **284	Obv. 30	-232 Dec 14	P	Y	
BM 41007	Rev. 9'	-225 Feb 6	P	Y	
BM 33655	Rev. 4–8	-225 Aug 1	O	Y	
BM 36402 + 36865		-214 Dec 25	O	Y	

Table A.1: Lunar eclipses contained in the Astronomical Diaries.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
BM 40116	7'	-209 Apr 9	P	N	
LBAT 320	Obv. 10'	-194 Jun 20	P	Y	cf. LBAT 1249 (Goal-year Text)
LBAT 324	Obv. 18'–19'	-193 Nov 5	O	Y	cf. LBAT 1436 (Eclipse Text)
BM 32349 + 32428	Rev. 2'	-185 Dec 6	P	N	
LBAT 335	Obv. 7'–9'	-184 Nov 24	O	Y	
LBAT 340 + 341	Rev. 4'–5'	-182 Oct 4	O	D	
LBAT 361 + 608 + 756 + 358	Rev. 11'	-172 Mar 21	P	Y	
BM 45645 + 45745	Rev. 12'–13'	-170 Aug 23	O	Y	
BM 40092	Rev. 10'	-169 Feb 16	P	Y	
LBAT 380 + 920	Rev. 8'	-162 Mar 30	O	N	cf. LBAT 1264 (Goal-year Text)
BM 36763 + 36891	Rev. 6'	-161 Aug 14	P	Y	cf. LBAT 1266 (Goal-year Text)
LBAT 385	Rev. 4'–5'	-159 Jan 26	O	Y	cf. LBAT 1436 (Eclipse Text)
LBAT *389	Obv. 10	-158 Jul 12	P	Y	
LBAT 390	Obv. 10	-158 Dec 7	P	D	
LBAT *393	Obv. 6'–7'	-156 Nov 15	O	Y	
LBAT 400	Obv. 5'–8'	-149 Jul 2	O	Y	
LBAT 874	Rev. 6'	-141 Aug 3	P	D	
LBAT 416 + 417 + 418	Rev. 15'	-140 Jul 22	P	Y	
LBAT 420	Obv. 12	-140 Dec 17	P	Y	
LBAT 422	Obv. 7'	-137 May 22	P	Y	
LBAT *424	Rev. 3'	-137 Nov 15	P	N	
LBAT 430 + 431	Rev. 2'	-136 Oct 5	P	Y	
LBAT 533	Rev. 8'	-134 Mar 20	O	Y	
LBAT 432	Rev. 16'–17'	-133 Mar 10	O	Y	
LBAT *435	Obv. 8'–9'	-133 Sep 3	O	Y	cf. LBAT 1134 (NS Almanac)
LBAT 437 + 436	Obv. 7'	-132 Jan 29	P	N	

Table A.1 (cont.): Lunar eclipses contained in the Astronomical Diaries.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT 728	6'–8'	-130 Jul 2	O	Y	
RM 701 + BM 41478 + 41646	Obv. 7'	-129 May 23	P	N	
BM 34112	Obv. 15'	-126 Apr 21	P	D	
BM 33024 + 33045 + 45745	Rev. 14–15	-123 Aug 13	O	Y	
BM 45947A	Rev. 6'	-122 Aug 2	O	N	
BM 33044 + 33047	Obv. 8'–10'	-122 Aug 2	O	N	
BM 35759 + 45621	Obv. 3'–5'	-119 Jun 1	O	Y	cf. LBAT 1442 (Eclipse Text)
BM 45702	Rev. 5'	-118 Oct 16	P	D	
BM 46029 + 46035 + 46084	Obv. 14'	-111 Jul 2	P	N	
BM 35086 + 46149 + 77619	Obv. 5'–6'	-109 Nov 5	O	Y	
LBAT *469	7–8	-108 May 1	O	Y	
LBAT *472 + 473 + *474	Rev. 8'	-106 Mar 11	P	Y	
BM 77670	5'–6'	-105 Feb 28	O	Y	
LBAT 477 + 479 + 480 + 481 + 627 + 777 + 909	Rev. 11'–12'	-105 Aug 24	O	Y	
LBAT 487	4'–5'	-96 Aug 14	P	N	
LBAT 492	6'–8'	-95 Aug 3	O	Y	
LBAT *494	Rev. 3–4	-93 Jul 13	O	N	
BM 41529 + 41546 + 13227 + Böhl 1332	Obv. 6'–7'	-90 Nov 5	O	N	
LBAT *504 + 505 + 506	Rev. 18'–20	-86 Feb 28	O	Y	cf. LBAT 1334 + ... (Eclipse Text)
BM 41018	Rev. 11'	-86 Aug 24	P	Y	
BM 46227	6'–8'	-80 Apr 21	O	Y	cf. LBAT 1444 (Eclipse Text)
BM 45659 + 45685	Rev. 5'	-76 Feb 9	P	Y	
LBAT 881	3'–7'	-75 Jan 28	O	N	
BM 45625	16'–18'	-72 Nov 16	O	Y	
LBAT 520	Obv. 7	-62 May 3	P	Y	

Table A.1 (cont.): Lunar eclipses contained in the Astronomical Diaries.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT 1413	Obv. 2	-746 Feb 6	O	N	Date Uncertain
	Obv. 3–4	-746 Aug 2	O	N	Date Uncertain
	Obv. 5	-745 Jan 26	O	N	Date Uncertain
	Obv. 6	-745 Jul 22	O	N	Date Uncertain
	Obv. 7	-744 Jan 15	P	N	Date Uncertain
	Obv. 8	-744 Jul 10	P	N	Date Uncertain
LBAT *1414	Obv. I', 1'–3'	-730 Apr 9	P	Y	
	Obv. II', 1'–3'	-712 Apr 19	O	Y	Wrongly filed?
	Obv. III', 1'–3'	-694 May 1	O	D	
	Rev. I', 1'–2'	-388 Oct 31	P	N	
	Rev. II', 1'–3'	-370 May 17	O	Y	
	Rev. II', 4'–14'	-370 Nov 11	O	Y	cf. LBAT 181 (Diary)
	Rev. III', 1'	-352 May 28	P	Y	
	Rev. III', 2'–10'	-352 Nov 22	O	N	
	Rev. IV', 1'–2'	-334 Dec 3	P	Y	
	Rev. V', 1'–4'	-316 Jun 18	O	Y	
	Rev. V', 5'–12'	-316 Dec 13	O	Y	
LBAT 1415 + 1416 + 1417	Obv. I', 1'	-702 Sep 23	P	N	
	Obv. I', 2'–5'	-701 Mar 20	O	N	
	Obv. II', 1–6	-685 Apr 22	O	Y	
	Obv. II', 8–9	-685 Oct 15	P	N	
	Obv. II', 1'–4'	-684 Oct 3	O	Y	
	Obv. II', 5'–6'	-683 Mar 30	P	D	
	Obv. III', 1–4	-667 May 2	P	Y	
	Obv. III', 5–6	-667 Oct 25	P	Y	
	Obv. III', 1'–3'	-666 Oct 15	O	D	
	Obv. III', 4'–6'	-665 Apr 10	O	D	
	Obv. IV', 1–4	-649 May 13	P	Y	
	Obv. IV', 5–8	-649 Nov 6	O	N	
	Obv. V', 1–6	-631 May 24	O	Y	
	Rev. I', 1'–2'	-414 Mar 26	P	Y	
	Rev. I', 3'–8'	-414 Sep 19	O	N	Wrongly filed?
	Rev. I', 9'–12'	-413 Mar 16	P	N	
	Rev. II', 1'	-397 Oct 12	P	N	
	Rev. II', 2'–8'	-396 Apr 5	O	Y	
	Rev. II', 9'–11'	-396 Sep 30	O	Y	Wrongly filed?
	Rev. II', 12'–13'	-395 Mar 26	P	Y	
	Rev. II', 14'–15'	-395 Sep 13	?	N	
	Rev. III', 1'–2'	-379 Oct 24	P	Y	
	Rev. III', 3'–9'	-378 Apr 17	O	Y	Wrongly filed?
	Rev. III', 10'–11'	-378 Oct 11	P	Y	
	Rev. III', 12'–20'	-377 Apr 6	O	Y	
	Rev. IV', 2'–5'	-359 Apr 17	O	N	
BM 38357	Obv. II, 7'–15'	-609 Sep 15	O	D	
LBAT *1419	Obv. I', 1'–8'	-608 Sep 4	O	D	
	Obv. II', 1'–2'	-590 Mar 22	O	Y	cf. LBAT *1420
	Obv. II', 3'–5'	-590 Sep 15	P	Y	cf. LBAT *1420
	Obv. II', 6'–7'	-589 Mar 12	P	D	cf. LBAT *1420
	Obv. III', 1'–8'	-572 Apr 2	O	Y	
	Obv. III', 9'–11'	-572 Sep 25	P	Y	
	Obv. III', 12'–13'	-571 Mar 22	?	N	
	Obv. IV', 2'–8'	-554 Oct 6	O	Y	
	Obv. IV', 9'	-553 Apr 3	?	N	
	Obv. V', 1'–3'	-536 Apr 23	O	N	
	Obv. V', 4'–10'	-536 Oct 17	O	Y	
	Rev. I', 1'–4'	-518 Oct 28	P	N	
	Rev. II', 1'–6'	-500 Nov 7	O	Y	
	Rev. III', 1'–6'	-482 Nov 19	O	Y	
	Rev. IV', 1'–3'	-464 Jun 5	O	Y	
	Rev. IV', 5'–9'	-464 Nov 29	O	N	
	Rev. V', 1'–2'	-446 Dec 11	?	N	

Table A.2: Lunar eclipses contained in the Eclipse Texts.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT *1420	Obv. I, 1	-603 Jun 13	P	N	
	Obv. I, 2	-603 Dec 6	P	N	
	Obv. I, 3	-602 May 3	P	N	
	Obv. I, 4–6	-602 Oct 27	O	Y	
	Obv. I, 7	-601 Apr 22	P	N	
	Obv. I, 7	-601 Oct 17	P	N	
	Obv. I, 8–10	-600 Apr 11	O	Y	
	Obv. I, 11	-600 Oct 5	P	N	
	Obv. I, 12	-599 Mar 31	P	N	Restoration
	Obv. I, 12	-599 Sep 24	P	N	
	Obv. I, 13–15	-598 Feb 20	O	Y	
	Obv. II, 1–2	-594 Nov 27	O	Y	
	Obv. II, 3–4	-593 May 23	O	Y	
	Obv. II, 4	-593 Nov 17	P	N	
	Obv. II, 5	-592 May 12	P	N	
	Obv. II, 5	-592 Nov 5	P	N	
	Obv. II, 6–7	-591 Apr 2	O	Y	
	Obv. II, 8	-591 Sep 26	P	N	
	Obv. II, 9	-590 Mar 22	O	Y	cf. LBAT *1419
	Obv. II, 10	-590 Sep 15	P	N	cf. LBAT *1419
	Obv. II, 11	-589 Mar 12	P	N	Restoration. cf. LBAT *1419
	Obv. II, 12	-589 Sep 4	P	N	
	Obv. II, 12	-588 Feb 29	P	N	
	Obv. II, 13	-588 Jul 25	P	N	
	Obv. II, 14–15	-587 Jan 19	O	Y	
	Obv. II, 16	-587 Jul 15	P	N	
	Obv. II, 17–18	-586 Jan 8	O	Y	
	Rev. III, 1'–2'	-579 Feb 19	O	N	
	Rev. III, 3'	-579 Aug 15	O	Y	
	Rev. III, 4'	-578 Feb 8	?	N	
	Rev. III, 5'	-578 Aug 4	P	N	
	Rev. III, 5'	-577 Jan 28	P	N	
	Rev. III, 6'	-577 Jun 25	P	N	
	Rev. III, 6'	-577 Dec 19	P	N	
	Rev. III, 7'–9'	-576 Jun 14	O	N	
	Rev. III, 10'–12'	-576 Dec 8	O	Y	
	Rev. III, 13'–14'	-575 Jun 3	O	Y	
LBAT 1421	II', 1'	-562 Mar 13	?	N	
	II', 2'–4'	-562 Sep 5	O	Y	
	II', 5'–8'	-561 Mar 3	O	Y	
BM 36879	Rev. I, 1'	-527 Nov 6	P	D	
	Rev. I, 2'	-526 Apr 4	P	N	
	Rev. I, 3'	-526 Sep 27	P	N	
	Rev. I, 4'	-525 Mar 24	P	Y	
	Rev. I, 5'–11'	-525 Sep 17	O	Y	
BM 33066	Rev. 19–20	-522 Jul 17	?	Y	
	Rev. 21–22	-521 Jan 10	?	Y	
LBAT 1426 + 1427	Rev. I', 1'–3'	-441 Mar 25	O	N	
	Rev. I', 6'	-440 Mar 13	P	N	Date uncertain
	Rev. I', 7'	-440 Aug 7	P	N	
	Rev. I', 8'–10'	-439 Feb 2	O	N	
	Rev. I', 11'	-439 Jul 28	P	N	
	Rev. II', 4'–5'	-423 Sep 28	O	Y	
	Rev. II', 6'	-422 Mar 27	P	N	Restoration
	Rev. II', 7'	-422 Aug 20	P	N	
	Rev. II', 8'	-421 Feb 13	P	D	
	Rev. II', 9'	-421 Aug 18	P	D	
	Rev. II', 10'–12'	-420 Feb 2	O	D	
	Obv. 1'	-409 Jun 28	P	Y	
	Obv. 3'–5'	-409 Dec 21	O	Y	
	Obv. 6'–7'	-408 Jun 16	O	N	
	Obv. 8'	-408 Nov 11	P	Y	Date uncertain
	Obv. 9'	-407 May 7	P	N	
	Obv. 10'–12'	-407 Oct 31	O	Y	

Table A.2 (cont.): Lunar eclipses contained in the Eclipse Texts.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
	Rev. III', 1–3	-406 Apr 26	P	N	
	Rev. III', 4–6	-406 Oct 21	O	Y	
	Rev. III', 7–8	-405 Apr 15	O	Y	
	Rev. III', 9–10	-405 Oct 10	O	Y	
LBAT *1429	I', 1'–2'	-382 Dec 23	P	N	
	I', 3'–4'	-381 Jun 18	O	N	
	I', 5'–6'	-381 Dec 12	O	N	
	II', 1'–3'	-363 Jan 2	O	N	
	II', 4'–5'	-363 Jun 29	O	Y	
	II', 6'–8'	-363 Dec 23	O	Y	
	II', 9'–10'	-362 Jun 18	O	Y	
LBAT 1452		-283 Mar 17	O	Y	
LBAT *1432	I'–3'	-279 Dec 26	P	N	
	4'–5'	-278 Jun 19	P	Y	
	6'–7'	-278 Nov 15	P	Y	
	8'–9'	-277 May 10	P	D	
	10'	-277 Nov 3	P	N	
LBAT 1436	Obv. II', 1	-194 Nov 16	P	Y	cf. LBAT 1249 (Goal-year Text)
	Obv. II', 2–3	-193 May 11	P	Y	
	Obv. II', 4–6	-193 Nov 5	O	Y	cf. LBAT 324 (Diary)
	Rev. I', 1'–3'	-159 Jan 26	O	Y	cf. LBAT 385 (Diary)
	Rev. I', 4'	-159 Jul 23	P	N	
LBAT 1437		-189 Feb 28	O	Y	
LBAT *1440		-153 Mar 21	O	Y	
LBAT 1441		-128 Nov 5	O	Y	
LBAT 1442		-119 Jun 1	O	Y	cf. BM 35759 + 45621 (Diary)
LBAT 1334 +	Obv. IV, 6'–8'	-88 Sep 15	O	D	
1435+1443	Rev. VII, 17'–20'	-86 Feb 28	O	Y	cf LBAT *504 + ... (Diary)
LBAT 1444	Obv.	-80 Apr 23	O	N	cf. BM 46227 (Diary)
LBAT **1445		-79 Apr 10	O	Y	
LBAT 1446		-79 Oct 5	O	Y	
LBAT 1447		-66 Jan 19	O	Y	Damaged copy of LBAT 1448
LBAT 1448		-66 Jan 19	O	Y	
LBAT 1449		-65 Jan 8	O	Y	
LBAT *1450		-65 Dec 28	O	Y	

Table A.2 (cont.): Lunar eclipses contained in the Eclipse Texts.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT 1366	Rev. 3'–8'	-250 Dec 4	O	N	
LBAT **1216	Obv. 1–2	-248 Apr 19	P	Y	cf. LBAT 267 (Diary)
	Obv. 5–6	-248 Oct 13	P	Y	
LBAT **1218	Rev. 3–5	-239 Nov 3	O	Y	
LBAT **1237	Rev. 48–53	-211 Apr 30	O	Y	
	Rev. 56–59	-211 Oct 24	O	Y	
LBAT 1249	Rev. 8'–9'	-194 Jun 20	P	Y	cf. LBAT 320 (Diary)
	Rev. 10'–12'	-194 Nov 16	P	Y	cf. LBAT 1436 (Eclipse Text)
LBAT 1251	Rev. 14–18	-189 Aug 23	O	Y	
	Rev. 23–26	-188 Feb 17	O	Y	
LBAT 1263	Rev. 8'–10'	-169 Aug 13	P	Y	
	Rev. 11'–12'	-168 Jan 7	P	Y	
LBAT 1264	Rev. 3'–9'	-162 Mar 30	O	Y	cf. LBAT 380 + 920 (Diary)
	Rev. 13'–15'	-162 Sep 23	P	Y	
	Rev. 15'–17'	-161 Feb 18	P	Y	
LBAT 1266	Rev. 14–17	-161 Aug 14	P	Y	cf. BM 36763 + 36891 (Diary)
	Rev. 20–22	-160 Feb 7	P	Y	
LBAT 1278	Rev. 3'–8'	-142 Feb 17	O	Y	
LBAT 1285	Rev. 17–23	-135 Apr 1	O	Y	
	Rev. 29–35	-135 Sep 24	O	D	
LBAT 1304	Rev. 3'	-49 Mar 2	O	Y	

Table A.3: Lunar eclipses contained in the Goal-Year Texts.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
MM 86.11.369	Obv. 10'	-241 Jun 1	P	D	
LBAT 1006	Rev. 16'	-217 Mar 9	P	N	
LBAT 1008	Rev. 14'	-214 Jan 5	P	Y	
LBAT 1020	Rev. 7'	-199 Mar 19	P	D	
LBAT 1022	Obv. 3'	-191 Apr 19	P	Y	
LBAT 1039	Rev. 5'	-138 Nov 26	P	D	
LBAT 1043	Obv. 18'	-132 Jul 24	P	N	cf. LBAT 1135 (Almanac)
LBAT 1047	Obv. 2'	-127 May 2	P	N	
LBAT 1057	Obv. 2'	-117 Apr 12	P	N	

Table A.4: Lunar eclipses contained in the Normal Star Almanacs.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT 1134	Obv. 12'	-133 Sep 3	P	Y	cf. LBAT *435 (Diary)
LBAT 1135	Obv. 9	-132 Jul 24	P	N	cf. LBAT 1043 (NS Almanac)
LBAT 1136	Rev. 5'	-131 Jan 17	P	Y	
LBAT 1137	Obv. 4	-128 May 12	P	N	
LBAT 1151	Obv. 5	-110 May 23	P	N	
LBAT 1153	Obv. 7'	-102 Jun 23	P	N	
LBAT 1155 + 1154	Obv. 7	-102 Jun 23	P	N	Copy of LBAT 1153
LBAT 1174	Obv. 7–8 Rev. 4	-75 Jul 24 -75 Dec 18	P P	Y N	
LBAT 1188 + 1189	Obv. 10	-11 Aug 5	P	N	
LBAT 1194	Obv. 2'	-6 Oct 8	P	N	
LBAT 1195	Obv. 1 Obv. 14	-6 Apr 14 -6 Oct 8	P P	N N	
LBAT 1193	Rev. 9	-5 Apr 4	P	N	

Table A.5: Lunar eclipses contained in the Almanacs.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
BM 37097 + 37211	Rev. 4'	-368 Apr 11	O	Y	
LBAT *218	Rev. 2–3	-366 Mar 20	P	N	
BM 32149 + 32866 + 32252	III, 28'	-366 Sep 14	?	N	
BM 36913	Rev. 6'	-356 Feb 29	O	D	cf. BM 71537 (Eclipse Text)
LBAT *189	Obv. 28	-345 Jan 29	P	N	
LBAT *198	Rev. 10	-332 Oct 27	P	Y	
BM 36761 + 36390	Obv. 12'	-330 Oct 5	P	Y	
LBAT *208	Rev. 13'	-322 Oct 7	O	N	
LBAT *210 + 211	Rev. 32	-321 Apr 2	P	N	
LBAT 212 + 213	Rev. 21'	-321 Sep 26	O	N	
BM 34616 + 45901	Obv. 21'	-302 Sep 25	P	Y	
BM 32272 + 32288 + 32422 + 32501 + 32624		-291 Aug 25	P	Y	
LBAT 232	Rev. 9–10	-280 Jan 30	O	Y	
BM 36710 + 92688 + 92689	Rev. 14'	-272 Mar 1	P	N	
LBAT 247	Obv. 2'	-266 Oct 17	P	Y	
BM 32245 + 32404	Obv. 11'	-261 Dec 21	?	N	
LBAT 255 + 256 + 885 + 895 + 985	Rev. 1	-255 Sep 16	O	Y	
LBAT 596 + 258	Rev. 11-12	-253 Jan 31	O	Y	
LBAT 267	Obv. 8'	-248 May 4	O	D	cf. LBAT *1216 (Goal-year Text)
BM 32889 + 32967 + 41614 + 41618	Rev. 3'	-246 Sep 7	P	Y	
BM 132276 + MNB 1884	Rev. 2'	-245 Aug 28	P	D	
LBAT 276	6'	-241 Jun 15	O	Y	cf. MM 86.11.369 (NS Almanac)
RM 720 + 732 + BM 41522	Obv. 3'	-240 Nov 28	O	Y	

Table A.6: Solar eclipses contained in the Astronomical Diaries.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT **284	Obv. 22	-232 Nov 30	P	Y	
LBAT 285 + 550	Obv. 13	-230 May 15	P	Y	
BM 41871	Rev. 10'	-228 Mar 25	P	Y	
BM 36889	Rev. 12'	-226 Mar 3	P	Y	
BM 41007	Rev. 15'	-225 Feb 20	P	N	
BM 33655	Obv. 11	-225 Jul 17	P	Y	
BM 35110 + 45725 + 45995 + 46145 + 46169 + 46189	Rev. 2'	-217 Feb 22	P	N	cf. LBAT 1006 (NS Almanac)
LBAT 299 + 300	Rev. 29	-209 Sep 18	P	Y	
LBAT 306	Obv. 6'	-202 May 6	O	D	
BM 36591	Obv. 6'	-200 Apr 13	P	Y	
LBAT 317 + 819	Obv. 2'	-195 Jun 16	P	N	
LBAT *322	Rev. 5'	-193 May 26	P	Y	
LBAT 324	Obv. 26'	-193 Nov 19	P	N	
BM 32951	6'	-189 Mar 14	O	N	cf. LBAT 1438 (Eclipse Text)
BM 45636 + 45876	Obv. 12'	- 186 Dec 31	P	N	
LBAT 348	Rev. 1'–2'	-179 Aug 17	O	N	
LBAT 361 + 608 + 756 + 358	Rev. 17'	-172 Apr 4	?	D	
LBAT *376	Obv. 13–14	-165 May 17	O	Y	
BM 35015 + 35332 + 55531	Obv. 12'	-164 Oct 29	P	Y	
LBAT 380 + 920	Rev. 8'	-162 Mar 15	P	N	
BM 33850 + 47720	Rev. 3	-162 Sep 8	P	Y	cf. LBAT 1264 (Goal-year Text)
LBAT 391	Obv. 15'	-156 May 7	P	N	
LBAT 403 + 404 + *405	Obv. 10'–11'	-144 Sep 19	P	Y	
LBAT 420	Obv. 28–29	-140 Dec 31	P	Y	
LBAT 430 + 431	Rev. 7	-136 Oct 26	P	Y	
LBAT *429	Rev. 13'–15'	-135 Apr 15	O	Y	cf. LBAT 1285 (Goal-year Text)

Table A.6 (cont.): Solar eclipses contained in the Astronomical Diaries.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT 432 + 434	Rev. 5'	-133 Feb 24	?	N	
LBAT *435	Obv. 3'	-133 Aug 19	?	Y	
LBAT 437 + 436	Obv. 16'–17'	-132 Feb 13	O	Y	cf. LBAT *1042 (NS Almanac)
LBAT 441	Rev. 10'	-131 Feb 1	P	Y	
RM 701 + BM 41478 + 41646	Obv. 13'	-129 Jun 7	P	N	
LBAT 447	Rev. 17'	-125 Sep 19	O	Y	
LBAT 448	Rev. 7'	-124 Apr 15	P	N	
LBAT 449	Rev. 16	-124 Sep 7	P	Y	cf. LBAT 1049 (NS Almanac)
LBAT 972 + 457	6'	-119 May 17	P	D	
LBAT 459	Obv. 14	-118 May 7	P	Y	
	Rev. 13'–14'	-118 Oct 31	P	Y	
LBAT 460	Rev. 17'	-111 Jun 18	O	Y	
LBAT *472 + 473 + *474	Rev. 12'	-107 Apr 6	P	Y	
LBAT 484	5'	-99 Oct 31	P	N	
LBAT 401	10'	-95 Aug 19	P	N	
LBAT 507 + 970	Rev. 10	-84 Jan 23	P	Y	
LBAT *513	Rev. 6'	-79 Sep 20	P	Y	
BM 43025 + 45689 + 46047	Rev. 26	-77 Aug 30	P	D	
LBAT 520	Obv. 12	-62 May 18	P	Y	

Table A.6 (cont.): Solar eclipses contained in the Astronomical Diaries.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
BM 36599+	Obv. 3	-474 Dec 5	P	N	
36941+36737+	Obv. 5	-473 May 31	P	N	
47912	Obv. 7	-473 Nov 25	P	Y	
	Obv. 9	-472 May 20	P	Y	
	Obv. 11	-472 Nov 13	P	N	
	Obv. 13	-471 May 9	P	Y	
	Obv. 15	-471 Nov 3	P	N	
	Obv. 18	-470 Mar 30	P	N	
	Obv. 20	-470 Sep 23	P	N	
	Obv. 22	-469 Mar 20	P	N	
	Obv. 24	-469 Sep 12	P	N	
	Obv. 26	-468 Mar 8	P	N	
	Obv. 28	-468 Sep 1	P	N	
	Obv. 30	-467 Feb 25	P	N	
	Obv. 32	-467 Aug 21	P	N	
	Obv. 35	-466 Jan 16	P	N	
	Obv. 37	-466 Jul 23	P	N	
	Obv. 39	-465 Jan 5	P	N	
	Obv. 41	-465 Jul 2	P	N	
	Obv. 43	-465 Dec 26	P	N	
	Rev. 1	-464 Jun 20	P	N	
	Rev. 3	-464 Dec 14	P	N	
	Rev. 5	-463 Jun 9	P	N	
	Rev. 8	-463 Nov 4	P	N	
	Rev. 10	-462 Apr 30	P	N	
	Rev. 12	-462 Oct 24	P	N	
	Rev. 14	-461 Apr 20	P	N	
	Rev. 16	-461 Nov 13	P	N	
	Rev. 18	-460 Apr 8	P	N	
	Rev. 20	-460 Oct 2	P	N	
	Rev. 23	-459 Feb 27	P	N	
	Rev. 25	-459 Aug 23	P	N	
	Rev. 27	-458 Feb 16	P	N	
	Rev. 29	-458 Aug 12	P	Y	
	Rev. 31	-457 Feb 5	P	N	
	Rev. 33	-457 Aug 2	P	Y	
	Rev. 35	-456 Jan 26	P	N	
	Rev. 37	-456 Jul 21	P	N	
BM 71537	Rev. I, 1	-376 Sep 4	?	N	Restoration
	Rev. I, 2–3	-375 Jan 30	P	N	Restoration
	Rev. I, 4–6	-375 Aug 24	P	N	Restoration
	Rev. I, 7	-374 Feb 18	P	N	
	Obv. I, 1–4	-374 Aug 13	P	N	
	Obv. I, 5–7	-373 Feb 7	P	N	
	Obv. I, 8–10	-373 Jul 4	P	N	
	Obv. I, 11–12	-373 Dec 29	P	N	
	Obv. I, 13–14	-372 Jun 23	P	N	Restoration
	Rev. II, 1	-358 Sep 15	P	N	Restoration
	Rev. II, 2–4	-357 Mar 11	P	N	
	Rev. II, 5–6	-357 Sep 4	P	Y	
	Rev. II, 7	-356 Feb 29	?	N	cf. BM 36913 (Diary)
	Obv. II, 1–4	-356 Aug 23	P	N	
	Obv. II, 5–6	-355 Feb 18	P	Y	
	Obv. II, 8–10	-355 Jul 16	P	N	
	Obv. II, 11-12	-354 Jan 8	P	N	
	Obv. II, 13–14	-354 Jul 4	P	N	

Table A.7: Solar eclipses contained in the Eclipse Texts.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
	Rev. III, 1	-340 Sep 26	P	N	Restoration
	Rev. III, 2–4	-339 Mar 24	P	D	
	Rev. III, 4–6	-339 Sep 15	?	N	
	Rev. III, 7	-338 Mar 11	P	N	
	Obv. III, 1–4	-338 Sep 4	O	D	
	Obv. III, 5–7	-337 Mar 1	P	N	
	Obv. III, 8	-337 Jul 24	P	N	
	Obv. III, 11	-336 Jan 20	P	N	
	Rev. IV, 2–4	-321 Apr 2	P	N	Restoration
	Rev. IV, 4–6	-321 Sep 26	?	N	Restoration
	Rev. IV, 7	-320 Mar 22	P	N	Restoration
	Obv. IV, 1–3	-320 Sep 14	P	N	Restoration
	Obv. IV, 6–7	-319 Mar 11	P	N	
	Obv. IV, 8–10	-319 Aug 4	P	N	
	Obv. IV, 11-12	-318 Jan 30	P	N	
LBAT 1438		-189 Mar 14	O	Y	cf. BM 32951 (Diary)
LBAT 1334 + 1435+1443	Rev. V, 1'–7'	-88 Sep 29	O	Y	
	Rev. V, 17'–18'	-87 Feb 24	P	N	Restoration
	Rec VI, 20'	-87 Aug 20	P	N	Restoration
	Rev. VII, 13'–14'	-86 Feb 14	P	Y	
LBAT 1456		-9 Jun 30	O	Y	

Table A.7 (cont.): Solar eclipses contained in the Eclipse Texts.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT **1216	Obv. 3–4	-248 May 4	O	Y	cf. LBAT 267 (Diary)
LBAT **1237		-211 May 15	P	Y	
LBAT 1249	Rev. 3'–7'	-194 Jun 6	O	Y	
	Rev. 13'–15'	-194 Nov 30	P	Y	
LBAT 1251	Rev. 18–20	-189 Sep 7	P	Y	
	Rev. 20–22	-188 Feb 2	P	Y	
LBAT 1263	Rev. 3'–7'	-169 Jul 28	O	Y	
	Rev. 13'–14'	-168 Jan 22	P	Y	
LBAT 1264	Rev. 10'–13	-162 Sep 8	P	Y	cf. BM 33850 + 47720 (Diary)
	Rev. 17'–19'	-161 Mar 5	P	Y	
LBAT 1266	Rev. 18–19	-161 Aug 28	P	Y	
LBAT 1278	Rev. 1'–2'	-143 Sep 8	P	Y	
	Rev. 9'–11'	-142 Mar 5	P	N	
LBAT 1285	Rev. 24–28	-135 Apr 15	O	Y	cf. LBAT *429 (Diary)
LBAT 1304	Rev. 1'–2'	-40 Feb 15	P	Y	

Table A.8: Solar eclipses contained in the Goal-Year Texts.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT *997 + 998	Rev. 12'–13'	-255 Mar 24	P	Y	
MM 86.11.369	Obv. 13'	-241 Jun 15	P	D	cf. LBAT 276 (Diary)
LBAT *1003	Obv. 8'	-229 May 5	P	Y	
LBAT 1005	Rev. 4'	-218 Apr 3	P	Y	
LBAT 1006	Rev. 13'	-217 Feb 22	P	N	cf. BM 35110 +... (Diary)
LBAT 1008	Obv. 6' Rev. 16'	-215 Jul 26 -214 Jan 20	P P	D N	
LBAT 1010	Rev. 11	-206 Jan 22	P	Y	
LBAT *1011	Obv. 10	-206 Jul 17	P	Y	
LBAT 1012	Rev. 5'	-205 Jan 11	P	Y	
LBAT *1013 + 1014	Rev. 13	-204 Jan 1	P	N	
LBAT 1018	Obv. 12'–13'	-204 Jun 25	P	Y	
LBAT 1020	Rev. 4'	-199 Mar 4	P	Y	
LBAT *1024	Obv. 5'	-183 May 6	P	Y	
LBAT 1034	Obv. 18'	-154 Oct 10	P	Y	
LBAT 1038	Rev. 7'	-139 Dec 21	P	D	
LBAT *1042	Rev. 20'	-132 Feb 13	P	N	cf. LBAT 437 + 436 (Diary)
LBAT 1043	Obv. 19'	-132 Aug 7	P	Y	
LBAT *1045 + 1046	Rev. 23'	-127 Apr 16	P	Y	
LBAT 1049	Obv. 7'	-124 Sep 7	P	D	cf. LBAT 449 (Diary)
LBAT 1056	Rev. 6	-119 Nov 11	P	Y	
LBAT 1057	Rev. 15'	-116 Mar 16	P	Y	
LBAT 1102	Rev. 4	-82 Nov 22	P	D	
BM 32247	Rev. 9'	-76 Jan 24	P	N	

Table A.9: Solar eclipses contained in the Normal Star Almanacs.

Tablet	Lines	Date of Eclipse	Obs. / Pred.	Times	Comments
LBAT 1127	Rev. 9'	-152 Feb 24	P	N	
LBAT 1137	Rev. 3	-128 Nov 20	P	Y	
LBAT 1141	Obv. 7'	-122 Jul 19	P	D	
LBAT 1153	Obv. 8	-102 Jul 8	P	Y	
LBAT 1157	Obv. 5'	-91 May 8	P	D	
LBAT 1159	Rev. 3'	-85 Dec 24	P	N	
LBAT 1160	Obv. 9'	-78 Sep 9	P	N	
	Rev. 10'	-77 Mar 4	P	Y	
LBAT 1169	Obv. 5'	-75 Jul 9	P	N	
LBAT 1174	Obv. 6	-75 Jul 9	P	N	
	Rev. 4	-74 Jan 3	P	N	
LBAT 1182	Obv. 4	-64 Jan 7	P	D	
	Rev. 2	-64 Dec 2	P	N	
LBAT 1183	Obv. 7	-63 Jun 25	P	N	
	Rev. 2	-63 Nov 21	P	N	
LBAT 1185	Rev. 7'	-28 Jan 5	P	N	
LBAT 1187	Obv. 6'	-14 Sep 22	P	N	
LBAT 1189	Obv. 8	-11 Jul 21	P	Y	
LBAT 1195	Obv. 2	-6 Apr 29	P	Y	
	Obv. 14	-6 Oct 22	P	Y	
LBAT 1193	Rev. 11	-5 Apr 18	P	N	
DT 143	Rev. 3	+37 Jan 5	P	Y	

Table A.10: Solar eclipses contained in the Almanacs.

Appendix B

Timed Chinese Eclipse Records

B.1 The *Sung-shu*

- 4 September 434 AD

  "Yuan Chia reign period, 11th year, 7th month, 16th day, night of the full Moon. A lunar eclipse was calculated for the hour of *mao*. It actually began on the 15th day at the 2nd call of the 4th watch, that is in the initial half of the hour of *ch'ou*. It became total at the 4th call, at 15 degrees to the end of *ying-shih*."
  [*Sung-shu*, 12]

- 8 January 437 AD

  "Yuan Chia reign period, 13th year, 12th month, 16th day, night of the full Moon. A lunar eclipse was calculated for the hour of *yu*. It actually began at the initial half of the hour of *hai*. At the 3rd call of the 1st watch it became total. This was at 4 degrees in *kuei*."
  [*Sung-shu*, 12]

- 28 December 437 AD

  "Yuan Chia reign period, 14th year, 11th month, 16th day, night of the full Moon. A lunar eclipse was calculated for the hour *hsu*. It actually began at the 4th call of the second watch, that is at the end of the hour *wei*. At the 1st call of the 3rd watch the eclipse became total. This was at 38 degrees in *ching*."
  [*Sung-shu*, 12]
  Note: The text contains a misprint giving the 12th instead of the 11th month.

- 23 June 438 AD

  "Yuan Chia reign period, 15th year, 5th month, 15th day, night of the full Moon. A lunar eclipse was calculated for the hour *hsu*. That day the sun began to reappear and that is all. The light had already started to reappear reaching $\frac{1}{4}$ eclipsed. This was at 16 degrees in *tou*."
  [*Sung-shu*, 12]

- 26 October 440 AD

  "Yuan Chia reign period, 17th year, 9th month, 16th day, night of the full Moon. A lunar eclipse was calculated for the start of the hour *tzu*. The eclipse actually began at the end of the 15th day at the 1st call of the 2nd watch. At the 3rd call it was $\frac{12}{15}$ eclipsed. This was at $1\frac{1}{2}$ degrees in *mao*."
  [*Sung-shu*, 12]

B.2 The *Sui-shu*

- 21 January 585 AD

"K'ai Huang reign period, 4th year, 12th month, 15th day, *kuei-mao*. According to the calendar, the moon was 3 degrees in *kuei*. At the calculated hour of *yu*, the moon should have been above the direction of *mao* and have been $\frac{9}{15}$ eclipsed, the loss starting from the north-west side. Now when observed, at the 1st rod of the 1st watch the eclipse started from the north-east side and $\frac{10}{15}$ was covered. At the 4th rod it began to reappear. At the 1st rod of the 2nd watch it was returned to fullness."

[*Sui-shu*, 17]

- 1 August 585 AD

"K'ai-Huang reign period, 5th year, 6th month, 30th day. According to the solar eclipse calendar (*T'ai-yang-kuei*) the sun should have been 6 degrees in *ch'i hsing*. At the calculated time of the start of the hour of *wu*, the Sun should have been $\frac{1}{15}$ eclipsed, the loss beginning from the south-west side. Now when observed, the Sun began to be eclipsed after the 6th mark of the hour *wu*. The loss came from the north-east side and the Sun was $\frac{6}{15}$ eclipsed. After the 1st mark of the hour *wei* it began to return. At the 5th mark it was returned to fullness."

[*Sui-shu*, 17]

- 6 July 586 AD

"K'ai Huang reign period, 6th year, 6th month, 15th day. According to the lunar eclipse calendar (*T'ai-yin-kuei*) at the calculated hour of *yu*, above the direction of *mao* the Moon should have been $\frac{9}{15}$ eclipsed, the loss starting from the south-west. At that time thick clouds covered the Moon and it was not seen. Between the hours of *ch'en* and *ssu*, the Moon could be seen through the clouds. It was already $\frac{2}{3}$ eclipsed, the loss starting from the north-east. The clouds then returned. Between the hours of *ssu* and *wu*, they parted a little and after the hour of *wu* it was seen within the clouds that the Moon was returned to fullness."

[*Sui-shu*, 17]

- 16 December 586 AD

"K'ai Huang reign period, 6th year, 10th month, 30th day, *ting-ch'ou*. According to the solar eclipse calendar (*T'ai-yang-kuei*) the Sun should have been at 9 degrees in *tou*. At the calculated time of a little before *ch'en*, the Sun should have been $\frac{9}{15}$ eclipsed, the loss starting from the north-east side. Now in the observations it was seen that when the Sun had risen 1 *chang* above the mountains, at the 2nd mark of the hour *ch'en*, it began to be eclipsed. The loss started from the west and the Sun was $\frac{2}{3}$ eclipsed. After the 2nd mark of the hour of *ch'en* it began to recover. It had already set at the 3rd mark in the hour of *ssu* before it returned to fullness."

[*Sui-shu*, 17]

- 25 April 590 AD

"K'ai Huang reign period, 10th year, 3rd month, 16th day, *kuei-mao*. According to the calendar the Moon should have moved to 7 degrees in *ti*. At the calculated hour of *hsu*, the Moon should have been above the direction *ch'en*, and $\frac{7}{15}$ should have been eclipsed, the loss starting from the north-east. Now when observed the Moon began to rise from the south already $\frac{1}{2}$ eclipsed. At the start of the direction of *ch'en* it was $\frac{2}{3}$ eclipsed before gradually reappearing. At the end of the direction *ch'en* it was already returned to fullness."

[*Sui-shu*, 17]

- 19 October 590 AD

"K'ai Huang reign period, 10th year ... According to the calendar, in the 9th month, on the 16th day *keng-tzu*, the Moon should have moved to 4 degrees in *wei*. At the calculated hour of *ch'ou*, the Moon should have been above *wei*. It should have been $\frac{3}{10}$ eclipsed, the loss starting from the east. Now when observed 2 marks after reaching the direction *wu*, the Moon was eclipsed, starting from the east, then towards the south. It was above the direction *wei*. The southern part was $\frac{4}{5}$ eclipsed. It gradually recovered and $1\frac{1}{2}$ marks after entering the direction *shen* it was returned to fullness."

[*Sui-shu*, 17]

- 28 August 592 AD

"K'ai Huang reign period, 12th year, 7th month, 15th day, *chi-wei*. According to the calendar, the Moon should have moved to 7 degrees in *shih*. At the calculated hour of *hsu*, the Moon should have been above the direction *ch'en*. It should have been $\frac{12}{15}$ eclipsed, the loss starting from the north-west. Now when observed at the 3rd rod of the 1st watch, the loss began from the north-west and it was $\frac{2}{3}$ eclipsed. The calendar comments agree."

[*Sui-shu*, 17]

- 17 August 593 AD

"K'ai Huang reign period, 13th year, 7th month, 16th day. According to the calendar the Moon should have moved to above the direction *shen*. It should have been less than $\frac{1}{2}$ of a fifteenth eclipsed. The loss should begin from the south-west. On the 15th night from the 4th watch the Moon was observed. Before the 1st rod of the 5th watch, the loss began from the north-west. It was more than half eclipsed. It set in clouds and was not seen."

[*Sui-shu*, 17]

- 23 July 594 AD

"K'ai-yuang reign period, 14th year, 7th month, 1st day. According to the calendar, at the calculated time after the hour of *ssu*, more than $12\frac{1}{2}$ fifteenths (of the Sun) should have been eclipsed. After the 3rd mark of *wei* the Sun was eclipsed, the loss starting on the north-west. It was $\frac{1}{2}$ eclipsed. It set in clouds and was not seen. For an instant it was suddenly seen, at the end when fullness reappeared, but then clouds screened it"

[*Sui-shu*, 17]

- 22 December 595 AD

"K'ai Huang reign period, 15th year, 11th month, 16th day *keng-wu*. According to the calendar, the Moon should have moved to 17 degrees in *chung*. At the calculated hour of *hai*, the Moon should have been above the direction *ssu*. It should have been $\frac{9}{15}$ eclipsed, the loss from the north-west. That night, at the 4th rod of the 1st watch, the Moon was above the direction *ch'en*, and it became eclipsed, the loss beginning on the south-east. At the 3rd rod in the 2nd watch, the Moon was above the direction *ssu*. It was $\frac{2}{3}$ eclipsed and gradually recovered. At the 1st rod in the 3rd watch, the Moon was above the direction *ping* and was returned to fullness."

[*Sui-shu*, 17]

- 11 December 596 AD

"K'ai Yuang reign period, 16th year, 11th month, 16th day *i-ch'ou*. According to the calendar, the Moon should have moved to 17 degrees in *ching*. At the calculated time of *ch'ou*, the Moon should have been above the direction *wei*. It should have been $\frac{12}{15}$ eclipsed, the loss starting on the south-east. On the 15th day, according to the observations, at the 1st rod of the 3rd watch, the Moon was above the direction *ping*. It was seen within the clouds already $\frac{3}{15}$ eclipsed, the loss starting on the east side. Above the direction *ting*, the eclipse became total. Afterwards it reappeared from the south-east side. At the 3rd rod of the 4th watch, the Moon was at the end of *wei* and was returned to fullness."

[*Sui-shu*, 17]

B.3 The *Chiu T'ang-shu*

- 5 August 761 AD

"[Shang Yuan reign period], 2nd year, 7th month, *kuei-wei*. On the first day of the month the Sun was eclipsed. All of the great stars were visible. Ch'u T'an, the Head of the Astronomy Bureau, proclaimed to the Emperor that on (the day) *kuei-wei*, the Sun was dimmed. The loss began after the 6th mark of *ch'en*. After the 1st mark of *ssu* it was total. It was returned to fullness at the start of the 1st mark of *wu*. This was at 4 degrees in *chang*."

[*Chiu T'ang-shu*, 36]

- 23 March 768 AD

"[Ta Li reign period,] 3rd year, 3rd month, *i-ssu*. On the first day of the month the Sun was eclipsed. From the hour of *wu* it began, and at the 1st mark the eclipse had reached $6\frac{1}{2}$ tenths."

[*Chiu T'ang-shu*, 36]

B.4 The *Sung-shih*

- 26 March 1168 AD

"Ch'ien Tao reign period, 4th year, 2nd month, the night of the full moon. At the 5th point of the 2nd watch the moon was eclipsed 9 divisions. It rose above the ground and returned to fullness. I ... said to the prime minister that the moon should have been totally eclipsed when it rose above the ground. The *Chi-yuan-li* also gave the eclipse as total when it rose above the ground. The light should have reappeared at the 2nd mark of the initial half of the hour of *hsu*, and it should have been returned to fullness at the 3rd mark of the central half of the hour of *hsu*. That evening, the moon was concealed by cloud at the time of moonrise. By the time of dusk, it was seen that the moon was already totally eclipsed. By the 3rd mark of the initial half of the hour of *hsu*, the shine had reappeared, and so we may know that the eclipse was total when it rose above the ground. It returned to fullness at the 3rd mark of the central half of the hour of *hsu*. This was at the 2nd point of the 2nd watch."

[*Sung-shih*, 82]

Note: The text contains a printing error giving the 5th instead of the 4th year.

- 12 June 1173 AD

"[Ch'ien tao reign period, 9th year,] 5th month. The Sun was eclipsed. Officials from the Calendar Making Bureau observed that the Sun was eclipsed $4\frac{1}{2}$ divisions. The loss began from the north-west at $5\frac{1}{2}$ marks in the hour of *wu*. The eclipse reached its maximum to the north at the 2nd mark of the initial half of *wei*. It was returned to fullness towards the north-east at the 1st mark of the initial half of *shen*."

[*Sung-shih*, 82]

- 18 April 1185 AD

  "Shun Hsi reign period, 12th year, 3rd month. At full Moon, the Moon was eclipsed. This was at the 2nd point of the 3rd watch, but the calendar gave the 2nd point of the 2nd watch. The loss was counted as 4 divisions, but the calendar gave a loss of 5 divisions."

  [*Sung-shih*, 82]

- 23 May 1202 AD

  "Chia T'ia reign period, 2nd year, 5th month, *chia-ch'en*. On the 1st day of the month the Sun was eclipsed. The loss of the Sun began at the 1st mark of the initial half of *wu*. It was returned to fullness at the initial mark of *wei*."

  [*Sung-shih*, 82]

  Note: An additional time of $3\frac{1}{2}$ marks in the initial half of *wei* for the maximum phase is reported by Beijing Observatory (1988: 198).

- 25 July 1245 AD

  "Shun Yu reign period, 5th year. Cheng, an astronomical official, calculated that the Sun would be eclipsed at the 3rd mark of the initial half of the hour *wei*, but it was observed at the 4th mark of the central half of the hour of *wei*. The loss was calculated as 8 divisions, but it was observed to be 6 divisions."

  [*Sung-shih*, 82]

B.5 The *Yuan-shih*

B.5.1 Solar Eclipses

- 6 February 547 AD

  "T'ai Ch'ing reign period, 1st year, *ting-mao*, 1st month, *chi-hai*, first day of the month, eclipse at the hour of *shen*. The *Shou-shih-li* gives the eclipse maximum at 1st mark of *shen*. The *Ta-ming-li* gives the loss beginning at 3rd mark of *shen*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is close."

  [*Yuan-shih*, 53]

- 11 July 576 AD

  "Ch'en dynasty, Ta Chien reign period, 8th year, *ping-shen*, 6th month, *wu-shen*, first day of the month, eclipse between the hour of *mao* and the 1st denary hour. The *Shou-shih-li* gives the eclipse maximum at 2nd mark of *mao*. The *Ta-ming-li* gives the eclipse maximum at 4th mark of *mao*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is far off."

  [*Yuan-shih*, 53]

- 27 November 680 AD

  "T'ang dynasty, Yung Lung reign period, 1st year, *keng-ch'en*, 11th month, *jen-shen*, first day of the month, eclipse maximum at the 4th mark of the hour of *ssu*. The *Shou-shih-li* gives the eclipse maximum at 7th mark of *ssu*. The *Ta-ming-li* gives the eclipse maximum at 5th mark of *ssu*. The *Shou-shih-li* is off. The *Ta-ming-li* is close."

  [*Yuan-shih*, 53]

- 16 November 861 AD

  "K'ai Yao reign period, 1st year, *hsin-ssu*, 10th month, *ping-yin*, first day of the month, eclipse maximum at the initial mark of the hour of *ssu*. The *Shou-shih-li* gives the eclipse maximum at 3rd mark of central half of *ch'en*. The *Ta-ming-li* gives the eclipse maximum at 1st mark of central half of *ch'en*. The *Shou-shih-li* is close. The *Ta-ming-li* is off."

  [*Yuan-shih*, 53]

- 4 May 691 AD

  "Ssu Sheng reign period, 8th year, *hsin-mao*, 4th month, *jen-yin*, first day of the month, eclipse maximum at the 2nd mark of the hour of *mao*. The *Shou-shih-li* gives the eclipse maximum at 8th mark of *yin*. The *Ta-ming-li* gives the eclipse maximum at initial mark of *mao*. Both calendars are fairly close."

  [*Yuan-shih*, 53]

- 23 May 700 AD

  "17th year, *keng-tzu*, 5th month, *chi-yu*, first day of the month, eclipse maximum at the initial half of the hour of *shen*. The *Shou-shih-li* gives the eclipse maximum at the 2nd mark of initial half of *ssu*. The *Ta-ming-li* gives the eclipse maximum at the initial mark of the central half of *ssu*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is far off."

  [*Yuan-shih*, 53]

- 26 September 702 AD

  "19th year, *jen-yin*, 9th month, *i-ch'ou*, first day of the month, eclipse maximum at the 3rd mark of the hour of *shen*. The *Shou-shih-li* gives the eclipse maximum at the 1st mark of *shen*. The *Ta-ming-li* gives the eclipse maximum at the 4th mark of *shen*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is close."

  [*Yuan-shih*, 53]

- 4 July 707 AD

  "Ching Lung reign period, 1st year, *ting-wei*, 6th month, *ting-mao*, first day of the month, eclipse maximum at the central half of the hour of *wu*. The *Shou-shih-li* gives the eclipse maximum at the 2nd mark of the central half of *wu*. The *Ta-ming-li* gives the eclipse maximum at the initial mark of the initial half of *wei*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is far off."

  [*Yuan-shih*, 53]

- 26 September 721 AD

  "K'ai Yuan reign period, 9th year, *hsin-yu*, 9th month, *i-ssu*, first day of the month, eclipse maximum after the 3rd mark of the central half of the hour of *wu*. The *Shou-shih-li* gives the eclipse maximum at the 1st mark of *wu*. The *Ta-ming-li* gives the eclipse maximum at the 2nd mark of *wu*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is close."

  [*Yuan-shih*, 53]

  Note: The text contains a printing error giving the year as the 1st instead of the 9th.

- 9 April 1046 AD

  "Sung dynasty, Ch'ing Li reign period, 6th year, *ping-hsu*, 3rd month, *hsin-ssu*, first day of the month, eclipse. Return of fullness at the 3rd mark of the central half of the hour of *shen*. The *Shou-shih-li* gives the return of fullness at the 3rd mark of the central half of *shen*. The *Ta-ming-li* gives the return of fullness at the 1st mark of the central half of *shen*. The *Shou-shih-li* is exact. The *Ta-ming-li* is fairly close."

  [*Yuan-shih*, 53]

- 5 February 1049 AD

  "Huang Yu reign period, 1st year, *chi-ch'ou*, 1st month, *chia-wu*, first day of the month, eclipse maximum at the central half of the hour of *wu*. The *Shou-shih-li* gives the eclipse maximum at the 2nd mark of the initial half of *wu*. The *Ta-ming-li* gives the eclipse maximum at the initial mark of the central half of *wu*. The *Shou-shih-li* is close. The *Ta-ming-li* is exact."

  [*Yuan-shih*, 53]

- 13 November 1053 AD

  "5th year, *kuei-ssu*, 10th month, *ping-shen*, first day of the month, eclipse maximum at the 1st mark of the hour of *wei*. The *Shou-shih-li* gives the eclipse maximum at the 3rd mark of *wei*. The *Ta-ming-li* gives the eclipse maximum at the initial mark of *wei*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is close."

  [*Yuan-shih*, 53]

- 10 May 1054 AD

  "Chih Ho reign period, 1st year, *chia-wu*, 4th month, *chia-wu*, first day of the month, eclipse maximum at the 1st mark of the central half of the hour of *shen*. The *Shou-shih-li* gives the eclipse maximum at the 1st mark of the central half of *shen*. The *Ta-ming-li* gives the eclipse maximum at the 2nd mark of the central half of *shen*. The *Shou-shih-li* is exact. The *Ta-ming-li* is close."

  [*Yuan-shih*, 53]

- 15 February 1059 AD

  "Chia Yu reign period, 4th year, *chia-ssu*, 1st month, *ping-shen*, first day of the month, eclipse. Returned to fullness at the 3rd mark of the hour of *wei*. The *Shou-shih-li* gives the return to fullness at the 2nd mark of the initial half of *wei*. The *Ta-ming-li* gives the return to fullness at the 2nd mark of the initial half of *wu*. Both calendars are close."

  [*Yuan-shih*, 53]

- 20 June 1061 AD

  "6th year, *hsin-ch'ou*, 6th month, *jen-tzu*, first day of the month, eclipse. Beginning of loss at the initial half of the hour of *wei*. The *Shou-shih-li* gives the beginning of loss at the initial mark of *wei*. The *Ta-ming-li* gives the beginning of loss at the 1st mark of *wei*. The *Shou-shih-li* is close. The *Ta-ming-li* is fairly close."

  [*Yuan-shih*, 53]

- 22 September 1066 AD

  "Chia Ping reign period, 3rd year, *ping-wu*, 9th month, *jen-tzu*, first day of the month, eclipse maximum at the 2nd mark of the hour of *wei*. The *Shou-shih-li* gives the eclipse maximum at the 3rd mark of *wu*. The *Ta-ming-li* gives the eclipse maximum at the 4th mark of *wu*. The *Shou-shih-li* is close. The *Ta-ming-li* is fairly close."

  [*Yuan-shih*, 53]

- 21 July 1069 AD

  "Hsi Ning reign period, 2nd year, *chi-yu*, 7th month, *i-ch'ou*, first day of the month, eclipse maximum at the 3rd mark of the hour of *ch'en*. The *Shou-shih-li* gives the eclipse maximum at the 5th mark of *ch'en*. The *Ta-ming-li* gives the eclipse maximum at the 4th mark of *ch'en*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is close."

  [*Yuan-shih*, 53]

- 14 December 1080 AD

  "Yuan Feng reign period, 3rd year, *keng-shen*, 11th month, *chi-ch'ou*, first day of the month, eclipse maximum at the 6th mark of the hour of *ssu*. The *Shou-shih-li* gives the eclipse maximum at the 5th mark of *wu*. The *Ta-ming-li* gives the eclipse maximum at the 2nd mark of *wu*. The *Shou-shih-li* is close. The *Ta-ming-li* is far off."

  [*Yuan-shih*, 53]

- 19 March 1094 AD

  "Shao Sheng reign period, 1st year, *chia-hsu*, 3rd month, *jen-shen*, first day of the month, eclipse maximum at the 6th mark of the hour of *wei*. The *Shou-shih-li* gives the eclipse maximum at the 5th mark of *wei*. The *Ta-ming-li* gives the eclipse maximum at the 5th mark of *wei*. Both calendars are close."

  [*Yuan-shih*, 53]

- 16 December 1107 AD

  "Ta Kuan reign period, 1st year, *ting-hai*, 11th month, *jen-tzu*, first day of the month, eclipse. Beginning of loss at the 2nd mark of the hour of *wei*, maximum at the 8th mark of *wei*, return to fullness at the 6th mark of *shen*. The *Shou-shih-li* gives the beginning of loss at the 3rd mark of *wei*, maximum at the initial mark of *shen*, and return to fullness at the 6th mark of *shen*. The *Ta-ming-li* gives the beginning of loss at the initial mark of *wei*, maximum at the 7th mark of *wei*, and return to fullness at the 5th mark of *shen*. The *Shou-shih-li* is close for beginning of loss and maximum and exact for return of fullness. The *Ta-ming-li* is fairly close for beginning of loss and close for maximum and return to fullness."

  [*Yuan-shih*, 53]

- 17 January 1162 AD

  "Shao Hsing reign period, 32rd year, *jen-wu*, 1st month, *wu-ch'en*, first day of the month, eclipse. Beginning of loss at the initial half of the hour of *shen*. The *Shou-shih-li* gives the beginning of loss at the 1st mark of *shen*. The *Ta-ming-li* gives the beginning of loss at the 7th mark of *wei*. Both calendars are close."

  [*Yuan-shih*, 53]

• 17 November 1183 AD

"Shun Hsi reign period, 10th year, *kuei-mao*, 11th month, *jen-hsu*, first day of the month, eclipse maximum at the 2nd mark of the central half of the hour of *ssu*. The *Shou-shih-li* gives the eclipse maximum at the 2nd mark of the central half of *ssu*. The *Ta-ming-li* gives the eclipse maximum at the 1st mark of central half of *ssu*. The *Shou-shih-li* is exact. The *Ta-ming-li* is close."
[*Yuan-shih*, 53]

• 12 April 1195 AD

"Ch'ing Yuang reign period, 1st year, *i-mao*, 3rd month, *ping-hsu*, first day of the month, eclipse. Beginning of loss at the 2nd mark of the initial half of the hour of *wu*. The *Shou-shih-li* gives the beginning of loss at the 1st mark of the initial half of *wu*. The *Ta-ming-li* gives the beginning of loss at the 2nd mark of the initial half of *wu*. The *Shou-shih-li* is close. The *Ta-ming-li* is exact."
[*Yuan-shih*, 53]

• 23 May 1202 AD

"Chia T'ai reign period, 2nd year, *jen-hsu*, 5th month, *chia-ch'en*, first day of the month, eclipse. Beginning of loss at the 1st mark of the initial half of the hour of *wu*. The *Shou-shih-li* gives the beginning of loss at the 3rd mark of the central half of *ssu*. The *Ta-ming-li* gives the beginning of loss at the 3rd mark of the initial half of *wu*. Both calendars are close."
[*Yuan-shih*, 53]

• 19 February 1216 AD

"Chia Ting reign period, 9th year, *ping-tzu*, 2nd month, *chia-shen*, first day of the month, eclipse maximum at the 4th mark of the central half of the hour of *shen*. The *Shou-shih-li* gives the eclipse maximum at the 3rd mark of the central half of *shen*. The *Ta-ming-li* gives the eclipse maximum at the 2nd mark of the central half of *shen*. The *Shou-shih-li* is close. The *Ta-ming-li* is fairly close."
[*Yuan-shih*, 53]

• 22 March 1243 AD

"Shun Yu reign period, 3rd year, *kuei-mao*, 3rd month, *ting-ch'ou*, first day of the month, eclipse maximum at the 2nd mark of the initial half of the hour of *ssu*. The *Shou-shih-li* gives the eclipse maximum at the 1st mark of the initial half of *ssu*. The *Ta-ming-li* gives the eclipse maximum at the initial mark of the initial half of *ssu*. The *Shou-shih-li* is close. The *Ta-ming-li* is fairly close."
[*Yuan-shih*, 53]

• 12 April 1260 AD

"1st year, *keng-shen*, 3rd month, *wu-ch'en*, first day of the month, eclipse maximum at the 2nd mark of the central half of the hour of *shen*. The *Shou-shih-li* gives the eclipse maximum at the 1st mark of the central half of *shen*. The *Ta-ming-li* gives the eclipse maximum at the 3rd mark of the initial half of *shen*. The *Shou-shih-li* is close. The *Ta-ming-li* is off."
[*Yuan-shih*, 53]
Note: Date given by Sivin (1997) who notes a dating error in the text.

- 28 October 1277 AD

"Chia Yuan reign period, 14th year, *ting-ch'ou*, 10th month, *ping-ch'en*, first day of the month, eclipse. Beginning of loss at the initial mark of the central half of the hour of *wu*. Eclipse maximum at the 1st mark of the initial half of *wei*. Return to fullness at the 2nd mark of the central half of *wei*. The *Shou-shih-li* gives the beginning of loss at the initial of the central half of *wu*. Eclipse maximum at the 1st mark of the initial half of *wei*. Return of fullness at the 1st mark of the central half of *wei*. The *Ta-ming-li* gives the beginning of loss at the 3rd mark of the central half of *wu*. Eclipse maximum at the 1st mark of the central half of *wei*. Return of fullness at the 2nd mark of the initial half of *shen*. The *Shou-shih-li* is exact for beginning of loss and maximum, and close for return of fullness. The *Ta-ming-li* is off for beginning of loss and far off for maximum and return to fullness."
[*Yuan-shih*, 53]

B.5.2 Lunar Eclipses

- 4 September 434 AD

"Sung dynasty, Yuan Chia reign period, 11th year, *chia-hsu*, 7th month, *ping-tzu*, full moon, eclipse. Beginning of loss at the 2nd call of the 4th watch. Eclipse total at the 4th call of the 4th watch. The *Shou-shih-li* gives the beginning of loss at the 3rd point of the 4th watch and totality at the 4th point of the 4th watch. The *Ta-ming-li* gives the loss beginning at the 2nd point of the 4th watch and totality at the 5th point of the 4th watch. The *Shou-shih-li* is close for beginning of loss and exact for totality. The *Ta-ming-li* is exact for beginning of loss and close for totality."
[*Yuan-shih*, 53]

- 8 January 437 AD

"13th year, *ping-tzu*, 12th month, *kuei-ssu*, full moon, eclipse total at the 3rd call of the 1st watch. The *Shou-shih-li* gives totality at the 3rd point of the 1st watch. The *Ta-ming-li* gives totality at the 4th point of the 1st watch. The *Shou-shih-li* is exact. The *Ta-ming-li* is close."
[*Yuan-shih*, 53]
Note: The text contains a printing error giving the cyclical day as *chi-ssu* instead of *kuei-ssu*.

- 28 December 437 AD

"14th year, *ting-ch'ou*, 11th month, *ting-hai*, full moon, eclipse. Beginning of loss at the 4th call of the 2nd watch. Eclipse total at the 1st call of the 3rd watch. The *Shou-shih-li* gives the beginning of loss at the 5th point of the 2nd watch and totality at the 2nd point of the 3rd watch. The *Ta-ming-li* gives the loss beginning at the 4th point of the 2nd watch and totality at the 2nd point of the 3rd watch. The *Shou-shih-li* is close for beginning of loss and for totality. The *Ta-ming-li* is exact for beginning of loss and close for totality."
[*Yuan-shih*, 53]

- 26 June 530

"Liang dynasty, Chang Ta T'ung reign period, 2nd year, *keng-hsu*, 5th month, *keng-yin*, full moon, eclipse at the hour of *tzu*. The *Shou-shih-li* gives the eclipse maximum at the initial mark of the central half of *tzu*. The *Ta-ming-li* gives the eclipse maximum at the initial mark of the central half of *tzu*. Both calendars are exact."
[*Yuan-shih*, 53]

- 4 May 543 AD

  "Ta T'ung reign period, 9th year, *kuei-hai*, 3rd month, *i-ssu*, full moon, eclipse. Beginning of loss at the 3rd call of the 3rd watch. The *Shou-shih-li* gives the beginning of loss at the 1st point of the 3rd watch. The *Ta-ming-li* gives the loss beginning at the 3rd point of the 3rd watch. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is exact."

  [*Yuan-shih*, 53]

- 28 August 592 AD

  "Sui dynasty, K'ai Huang reign period, 12th year, *jen-tzu*, 7th month, *chi-wei*, full moon, eclipse. Beginning of loss at the 3rd call of the 1st watch. The *Shou-shih-li* gives the beginning of loss at the 4th point of the 1st watch. The *Ta-ming-li* gives the loss beginning at the 5th point of the 1st watch. The *Shou-shih-li* is close. The *Ta-ming-li* is fairly close."

  [*Yuan-shih*, 53]

- 22 December 595 AD

  "15th year, *i-mao*, 11th month, *keng-wu*, full moon, eclipse. Beginning of loss at the 4th point of the 1st watch. Maximum at the 3rd point of the 2nd watch. Return to fullness at the 1st point of the 3rd watch. The *Shou-shih-li* gives the beginning of loss at the 3rd point of the 1st watch, maximum at the 2nd point of the 2nd watch, and return to fullness at the 5th point of the 2nd watch. The *Ta-ming-li* gives the loss beginning at the 5th point of the 1st watch, maximum at the 3rd point of the 2nd watch, and return to fullness at the 5th point of the 2nd watch. The *Shou-shih-li* is close for beginning of loss, maximum, and return to fullness. The *Ta-ming-li* is close for beginning of loss and return to fullness and exact for maximum."

  [*Yuan-shih*, 53]

- 10 December 596 AD

  "16th year, *ping-ch'en*, 11th month, *chia-tzu*, full moon, eclipse. Return to fullness at the 3rd rod of the 4th watch. The *Shou-shih-li* gives the return to fullness at the 4th point of the 4th watch. The *Ta-ming-li* gives the return to fullness at the 5th point of the 4th watch. The *Shou-shih-li* is close. The *Ta-ming-li* is fairly close."

  [*Yuan-shih*, 53]

- 28 January 948 AD

  "Later Han dynasty (of the 5 dynasties), T'ien Fu reign period, 12th year, *ting-wei*, 12th month, *i-wei*, full moon, eclipse. Beginning of loss at the 4th point of the 4th watch. The *Shou-shih-li* gives the beginning of loss at the 5th point of the 4th watch. The *Ta-ming-li* gives the beginning of loss at the 1st point of the 4th watch. The *Shou-shih-li* is close. The *Ta-ming-li* is fairly close."

  [*Yuan-shih*, 53]

- 8 December 1052 AD

  "Sung dynasty, Huang Yu reign period, 4th year, *jen-ch'en*, 11th month, *ping-ch'en*, full moon, eclipse. Beginning of loss at the 4th mark of *yin*. The *Shou-shih-li* gives the beginning of loss at the 2nd mark of *yin*. The *Ta-ming-li* gives the beginning of loss at the 1st mark of *yin*. The *Shou-shih-li* is fairly close. The *Ta-ming-li* is off."

  [*Yuan-shih*, 53]

• 8 November 1063 AD

"Chia Yu reign period, 8th year, *kuei-mao*, 10th month, *kuei-wei*, full moon, eclipse maximum at the 7th mark of *mao*. The *Shou-shih-li* gives the maximum at the initial mark of *ch'en*. The *Ta-ming-li* gives the maximum at the initial mark of *ch'en*. Both calendars are close."
[*Yuan-shih*, 53]

• 30 December 1069 AD

"Hsi Ning reign period, 2nd year, *chi-yu*, intercalary 11th month, *tung-wei*, full moon, eclipse. Beginning of loss at the 6th mark of *hai*. Maximum at the 5th mark of *tzu*. Return to fullness at the 4th mark of *ch'ou*. The *Shou-shih-li* gives the beginning of loss at the 6th mark of *hai*, maximum at the 5th mark of *tzu*, and return to fullness at the 3rd mark of *ch'ou*. The *Ta-ming-li* gives the loss beginning at the initial mark of *tzu*, maximum at the 6th mark of *tzu*, and return to fullness at the 4th mark of *ch'ou*. The *Shou-shih-li* is exact for beginning of loss and maximum and close for the return to fullness. The *Ta-ming-li* is fairly close for beginning of loss, close for maximum, and exact for return to fullness."
[*Yuan-shih*, 53]

• 9 December 1071 AD

"4th year, *hsin-hai*, 11th month, *ping-shen*, full moon, eclipse. Beginning of loss at the 2nd mark of *mao*. Maximum at the 6th mark of *mao*. The *Shou-shih-li* gives the beginning of loss at the initial mark of *mao*, and maximum at the 5th mark of *mao*. The *Ta-ming-li* gives the loss beginning at the 4th mark of *mao*, and maximum at the 7th mark of *mao*. Both calendars are fairly close for beginning of loss and close for maximum."
[*Yuan-shih*, 53]

• 24 April 1073 AD

"6th year, *kuei-jen*, 3rd month, *wu-wu*, full moon, eclipse. Beginning of loss at the 1st mark of *hai*. Maximum at the 6th mark of *hai*. Return to fullness at the 4th mark of *tzu*. The *Shou-shih-li* gives the beginning of loss at the 7th mark of *hsu*, maximum at the 5th mark of *hai*, and return to fullness at the 3rd mark of *tzu*. The *Ta-ming-li* gives the loss beginning at the 2nd mark of *hai*, maximum at the 7th mark of *hai*, and return to fullness at the 4th mark of *tzu*. The *Shou-shih-li* is fairly close for beginning of loss and close for maximum and return to fullness. The *Ta-ming-li* is close for beginning of loss and maximum, and exact for return to fullness."
[*Yuan-shih*, 53]

• 7 October 1074 AD

"7th year, *chia-yin*, 9th month, *chi-yu*, full moon, eclipse. Beginning of loss at the 5th point of the 4th watch. Eclipse total at the 3rd point of the 5th watch. The *Shou-shih-li* gives the beginning of loss at the 5th point of the 4th watch and totality at the 3rd point of the 5th watch. The *Ta-ming-li* gives the loss beginning at the 3rd point of the 4th watch and totality at the 2nd point of the 5th watch. The *Shou-shih-li* is exact for beginning of loss and totality. The *Ta-ming-li* is fairly close for beginning of loss and close for totality."
[*Yuan-shih*, 53]

- 21 January 1106 AD

  "Ch'ung Ning reign period, 4th year, *i-yu*, 12 month, *wu-yin*, full moon, eclipse. Maximum at the 3rd mark of *yu*. Return to fullness at the initial mark of *hsu*. The *Shou-shih-li* gives the maximum at the 1st mark of *yu*, and return to fullness at the 7th mark of *yu*. The *Ta-ming-li* gives the maximum at the 3rd mark of *yu*, and return to fullness at the 2nd mark of *hsu*. The *Shou-shih-li* is fairly close for maximum and return to fullness. The *Ta-ming-li* is exact for maximum and fairly close for return to fullness."

  [*Yuan-shih*, 53]

- 7 April 1270 AD

  "Present (Yuan) dynasty, Chih Yuan reign period, 7th year, *keng-wu*, 3rd month, *i-mao*, full moon, eclipse. Beginning of loss at the 3rd mark of *ch'ou*. Maximum at the initial mark of *yin*. Return to fullness at the 6th mark of *yin*. The *Shou-shih-li* gives the beginning of loss at the 2nd mark of *ch'ou*, maximum at the initial mark of *yin*, and return to fullness at the 6th mark of *yin*. The *Ta-ming-li* gives the loss beginning at the 4th mark of *ch'ou*, maximum at the 1st mark of *yin*, and return to fullness at the 7th mark of *yin*. The *Shou-shih-li* is exact for beginning of loss, maximum, and return to fullness. The *Ta-ming-li* is close for beginning of loss, maximum, and return to fullness."

  [*Yuan-shih*, 53]

- 10 August 1272 AD

  "9th year, *jen-shen*, 7th month, *hsin-wei*, full moon, eclipse. Beginning of loss at the initial mark of *ch'ou*. Maximum at the 6th mark of *ch'ou*. Return to fullness at the 3rd mark of *yin*. The *Shou-shih-li* gives the beginning of loss at the 7th mark of *tzu*, maximum at the 4th mark of *ch'ou*, and return to fullness at the 1st mark of *yin*. The *Ta-ming-li* gives the loss beginning at the 2nd mark of *ch'ou*, maximum at the 6th mark of *ch'ou*, and return to fullness at the 2nd mark of *yin*. The *Shou-shih-li* is close for beginning of loss and fairly close for maximum and return to fullness. The *Ta-ming-li* is fairly close for beginning of loss, exact for maximum, and close for return to fullness."

  [*Yuan-shih*, 53]

- 18 May 1277 AD

  "14th year, *ting-ch'ou*, 4th month, *kuei-yu*, full moon, eclipse. Beginning of loss at the 6th mark of *tzu*. Totality at the 3rd mark of *ch'ou*. Begin to reappear at the 5th mark of *ch'ou*. Return to fullness at the 4th mark of *yin*. The *Shou-shih-li* gives the beginning of loss at the 6th mark of *tzu*, totality at the 4th mark of *ch'ou*, maximum at the 5th mark of *ch'ou*, reappearance of light at the 6th mark of *ch'ou*, and return to fullness at the 4th mark of *yin*. The *Ta-ming-li* gives the loss beginning at the initial mark of *ch'ou*, totality at the 7th mark of *ch'ou*, maximum at the 7th mark of *ch'ou*, reappearance of light at the 8th mark of *ch'ou*, and return to fullness at the 6th mark of *yin*. The *Shou-shih-li* is exact for beginning of loss, maximum, and return to fullness, and close for totality and reappearance of light. The *Ta-ming-li* is fairly close for beginning of loss, maximum, and return to fullness, far off for totality and close for reappearance of light."

  [*Yuan-shih*, 53]

- 29 March 1279 AD

  "16th year, *chi-mao*, 2nd month, *kuei-ssu*, full moon, eclipse. Beginning of loss at the 5th mark of *tzu*. Maximum at the 2nd mark of *ch'ou*. Return to fullness at the 7th mark of *ch'ou*. The *Shou-shih-li* gives the beginning of loss at the 5th mark of *tzu*, maximum at the 2nd mark of *ch'ou*, and return to fullness at the 7th mark of *ch'ou*. The *Ta-ming-li* gives the loss beginning at the 7th mark of *tzu*, maximum at the 3rd mark of *ch'ou*, and return to fullness at the 7th mark of *ch'ou*. The *Shou-shih-li* is exact for beginning of loss, maximum, and return to fullness. The *Ta-ming-li* is fairly close for beginning of loss, exact for maximum and return to fullness."

[*Yuan-shih*, 53]

Note: The text contains a printing error giving the cyclical day as *kuei-yu* instead of *kuei-ssu*.

- 21 October 1279 AD

  "8th month, *chi-ch'ou*, full moon, eclipse. Beginning of loss at the 5th mark of *ch'ou*. Maximum at the initial mark of *yin*. Return to fullness at the 4th mark of *yin*. The *Shou-shih-li* gives the beginning of loss at the 3rd mark of *ch'ou*, maximum at the initial mark of *yin*, and return to fullness at the 4th mark of *yin*. The *Ta-ming-li* gives the loss beginning at the 7th mark of *ch'ou*, maximum at the 2nd mark of *yin*, and return to fullness at the 4th mark of *yin*. The *Shou-shih-li* is fairly close for beginning of loss and exact for maximum and return to fullness. The *Ta-ming-li* is fairly close for beginning of loss and maximum, and exact for return to fullness."

  [*Yuan-shih*, 53]

- 10 October 1280 AD

  "17th year, *keng-ch'en*, 8th month, *chia-shen*, full moon, eclipse in daylight. Return to fullness at the 1st mark of *hsu*. The *Shou-shih-li* gives the return to fullness at the 1st mark of *hsu*. The *Ta-ming-li* gives the return to fullness at the 4th mark of *hsu*. The *Shou-shih-li* is exact. The *Ta-ming-li* is close."

  [*Yuan-shih*, 53]

B.6 The *Wen-hsien T'ung-k'ao*

B.6.1 Solar Eclipses

- 15 February 1040 AD

  "Pao Yuan reign period, 3rd year, 1st month, *ping-ch'en*. On the 1st day of the month (the Sun) was eclipsed 6 divisions. At the 1st mark of *shen* it was returned (to fullness)."

  [*Wen-hsien T'ung-k'ao*, 283]

  Note: The text contains a misprint giving the 1st instead of the 3rd year.

- 9 April 1046 AD

  "[Ch'ing Li reign period,] 6th year, 3rd month, *hsin-ssu*. On the 1st day of the month (the Sun) was eclipsed $4\frac{1}{2}$ divisions. It was returned (to fullness) at the 3rd mark of *shen*."

  [*Wen-hsien T'ung-k'ao*, 283]

- 24 November 1052 AD

  "[Huang Yu reign period,] 4th year, 11th month, *jen-yin*. On the 1st day of the month (the Sun) was eclipsed by a little more than 2 divisions. It was returned (to fullness) at the 1st mark of *wei*."

  [*Wen-hsien T'ung-k'ao*, 283]

- 13 November 1053 AD

  "[Huang Yu reign period,] 5th year, 10th month, *ping-shen*. On the 1st day of the month, at the 1st mark of the central half of *wei*, (the Sun) was eclipsed by $4\frac{1}{2}$ divisions."

  [*Wen-hsien T'ung-k'ao*, 283]

- 10 May 1054 AD

  "Chih Ho reign period, 1st year, 4th month, *chia-wu*. On the 1st day of the month, (the Sun) was eclipsed. It waned by more than 9 divisions from the south-west. At the 1st mark of the central half of *shen*, it reached its maximum. That day, it rained..."
  [*Wen-hsien T'ung-k'ao*, 283]

- 15 February 1059 AD

  "[Chia Yu reign period,] 4th year, 1st month, *ping-shen*. On the 1st day of the month (the Sun) was eclipsed by more than 3 divisions. It was returned to fulness at the 3rd mark of the initial half of *wei*."
  [*Wen-hsien T'ung-k'ao*, 283]

- 20 June 1061 AD

  "[Chia Yu reign period,] 6th year, 6th month, *jen-tzu*. On the 1st day of the month, at the 1st mark in *wei*, (the Sun) was eclipsed 4 divisions. It then set and was not seen."
  [*Wen-hsien T'ung-k'ao*, 283]

- 19 March 1094 AD

  "[Yuan Yu reign period,] 9th year, 3rd month, *jen-shen*. On the 1st day of the month, according to the Astronomer Royal, the Sun should have been eclipsed, but on account of thick clouds it was not seen. The loss began (to be seen) at the 3rd mark of *wei*. It was seen through the clouds that the Sun was eclipsed on the south-western side in excess of 1 division. At the 6th mark it reached a maximum of 7 divisions. On account of the clouds, its recovery was not seen."
  [*Wen-hsien T'ung-k'ao*, 283]

B.6.2 Lunar Eclipses

- 8 November 1063 AD

  "Chia Yu reign period, 8th year, 10th month, *kuei-wei*. (The Moon) was totally eclipsed. The eclipse reached its maximum at the 7th mark of *mao*. It then set and was not seen."
  [*Wen-hsien T'ung-k'ao*, 285]

- 3 March 1067 AD

  "Reign of Shen Tsung, Chih Ping reign period, 4th year, 2nd month, *ch-ia-wu*. The Moon was eclipsed. At the 4th mark of *ch'ou*, the loss was seen from the west. This was at the 5th degree of *chi*. By the 6th mark, the eclipse had reached its maximum of more than 8 divisions. It then set in the direction *yu* and was not seen."
  [*Wen-hsien T'ung-k'ao*, 285]

- 15 August 1068 AD

  "Hsi Ning reign period, 1st year, 7th month, *i-yu*. The Moon was eclipsed at the 5th mark in *ch'ou*. This was at 10 degrees in *wei*. The loss was seen from the north-eastern side. It was eclipsed $2\frac{1}{2}$ divisions and then set and was not seen."
  [*Wen-hsien T'ung-k'ao*, 285]

- 30 December 1069 AD

  "[Hsu Ning reign period], 2nd year, intercalary 11th month, *ting-wei*. The Moon was eclipsed. At the 1st mark of *hai*, the loss was seen on the north-eastern side. At the initial mark of *tzu*, the eclipse reached its maximum of 8 divisions. This was within *ching*. At the 3rd mark it was returned (to fullness)."
  [*Wen-hsien T'ung-k'ao*, 285]

- 9 December 1071 AD

  "[Hsu Ning reign period, 4th year,] 11th month, *ping-shen*. The Moon was eclipsed at the 2nd mark of *mao*. The loss passed from the south-east side to the west side. At the 6th mark, the eclipse reached its maximum of $4\frac{1}{2}$ divisions. This was at 1 degree in *tung-ching*. As dawn broke, the Moon set, and the end of the eclipse could not be discerned."
  [*Wen-hsien T'ung-k'ao*, 285]

- 24 April 1073 AD

  "[Hsu Ning reign period,] 6th year, 3rd month, *wu-wu*. The Moon was eclipsed at the 1st mark on *hai*. The loss was seen from the south-east. At the 6th mark, the eclipse reached its maximum of 7 divisions. At the 4th mark in *tzu*, it was returned (to fullness)."
  [*Wen-hsien T'ung-k'ao*, 285]

- 18 October 1073 AD

  "[Hsu Ning reign period, 6th year,] 9th month, *i-mao*. The Moon was eclipsed at the 4th mark of *ch'ou*. The loss was seen on the north-eastern side. At the 1st mark of *yin*, the eclipse reached its maximum of 6 divisions. It had recovered to 3 divisions short of fullness when it set and its return (to fullness) was not seen."
  [*Wen-hsien T'ung-k'ao*, 285]

- 7 October 1074 AD

  "[Hsu Ning reign period,] 7th year, 9th month, *chi-yu*. The Moon was eclipsed. At the 1st mark of *ch'ou* the loss began on the eastern side. At the 6th mark, the eclipse reached its maximum. This was at 2 degrees in *lou*. Dawn broke and its return (to fullness) was not seen."
  [*Wen-hsien T'ung-k'ao*, 285]

- 10 February 1077 AD

  "[Hsu Ning reign period,] 10th year, 1st month, *ping-yin*. The Moon was eclipsed. At the 3rd mark in *tzu*, the loss began on the south-eastern side. At the 7th mark, the eclipse reached its maximum of 7 divisions. This was in *chang*. At the 3rd mark of *ch'ou* it was returned (to fullness)."
  [*Wen-hsien T'ung-k'ao*, 285]

- 30 January 1078 AD

  "Yuan Feng reign period, 1st year, 1st month, *keng-shen*. The Moon was eclipsed at the 5th mark in *ch'ou*. It was seen on the south-eastern side."
  [*Wen-hsien T'ung-k'ao*, 285]

- 27 July 1078 AD

"[Yuan Feng reign period, 1st year,] 6th month, *wu-wu*. The Moon was eclipsed. At the 1st mark of *hsu* it was seen through the clouds in the east to have reached a magnitude of $7\frac{1}{2}$ divisions. At the 2nd mark the eclipse became total. This was in *hsu*. At $3\frac{1}{2}$ marks in *hai*, it was returned (to fullness)."

[*Wen-hsien T'ung-k'ao*, 285]

Note: The text contains a misprint giving the cyclical day as *hsu-wu* instead of *wu-wu*.

- 25 May 1081 AD

"[Yuan Feng reign period,] 4th year, 4th month, *hsin-wei*. The Moon was totally eclipsed. At the 2nd mark of *hsu* it rose from out of the gloom with 1 division on the east side remaining bright. This left 9 divisions on the west side covered. This was within *wei*. At the 6th mark it was restored."

[*Wen-hsien T'ung-k'ao*, 285]

- 8 November 1082 AD

"[Yuan Feng reign period,] 5th year, 10th month, *kuei-hai*. The Moon was eclipsed. From the 2nd mark of *yu*, the loss was seen from the north. At the 7th mark, the eclipse reached a maximum of 3 divisions. This was at a little more than 7 degrees in *mao*. At the 3rd mark of *hsu* it was returned (to fullness)."

[*Wen-hsien T'ung-k'ao*, 285]

- 6 September 1085 AD

"[Yuan Feng reign period,] 8th year, 8th month, *ping-tzu*. The Moon was eclipsed. At the 3rd mark of *hsu* the loss began. At the 7th mark the eclipse was total. At the 1st mark of *tzu* it was returned (to fullness)."

[*Wen-hsien T'ung-k'ao*, 285]

- 6 July 1088 AD

"[Reign of Che Tsung, Yuan Yu reign period], 1st year, 12th month, *wu-hsu*. The Moon was eclipsed. The loss began at the 5th mark of *hai*. At the 6th mark of *tzu* the eclipse was total. At the 4th mark of *ch'ou* it was returned (to fullness). This was within *tou*."

[*Wen-hsien T'ung-k'ao*, 285]

- 25 June 1089 AD

"[Yuan Yu reign period], 4th year, 5th month, *chia-shen*. The Moon was eclipsed, but the beginning was not seen on account of thick clouds. At the initial mark of ch'ou, the eclipse had reached 9 divisions. This was within *tou*. At the 6th mark, it was returned (to fullness)."

[*Wen-hsien T'ung-k'ao*, 285]

- 24 April 1092 AD

"[Yuan Yu reign period], 7th year, 3rd month, *wu-hsu*. The Moon was eclipsed. The loss began at the 1st mark of the initial half of *hai*. At the 7th mark, the eclipse was total. At the 7th mark of *tzu*, it was restored to fullness. The eclipse reached its maximum within *ti*."

[*Wen-hsien T'ung-k'ao*, 285]

- 30 January 1097 AD

"Shao Sheng reign period, 4th year, 1st month, *keng-tzu*. The Moon was eclipsed but on account of clouds the beginning of loss could not be seen. By the 7th mark of *yu*, the eclipse had reached 3 divisions. At the 1st mark of *hsu*, the eclipse had reached 4 divisions. During the return (to fullness), the clouds returned and veiled (the Moon)."
[*Wen-hsien T'ung-k'ao*, 285]

- 5 June 1099 AD

"Yuan Fu reign period, 2nd year, 5th month, *ping-chen*. The Moon was eclipsed at the 3rd mark of *tzu*. At the 2nd mark of *ch'ou* the eclipse was total. At the 2nd mark of *yin*, it was returned (to fullness). This was within *chi*."
[*Wen-hsien T'ung-k'ao*, 285]

- 30 November 1099 AD

"[Yuan Fu reign period, 2nd year,] 10th month, *chia-yin*. The Moon was eclipsed. The loss began at the 4th mark of *hai*. At the 4th mark of *tzu*, the eclipse was total. At the 4th mark of *ch'ou*, it was returned (to fullness). This was in *shen*."
[*Wen-hsien T'ung-k'ao*, 285]

B.7 Other sources

- 6 February 1068 AD

"The Sun was eclipsed. According to the Astronomers, that day at the 8th mark of the hour of *ssu*, the Sun waned, the loss beginning from the south-western side. After the 5th mark in the hour of *wu*, the eclipse had reached (a maximum) of slightly less than 6 divisions. At the 3rd mark in the hour of *wei*, it was returned to fullness."
[*Sung-hui-yao Chi-k'ao*]

- 11 May 1100 AD

"The Astronomer Royal proclaimed that the Sun was eclipsed 4 divisions from the north-west in the initial half of the hour of *ch'en*. At the 3rd mark of the central half of *ssu*, it was returned to fullness."
[*Sung-hui-yao Chi-k'ao*]

- 10 July 1572 AD

"... the Sun was eclipsed from the 3rd mark of the central half of *mao* to the 3rd mark of the initial half of *ssu*. It was not wholly divided into a half. The orbit brought it within *ching*."
[*Ming-shen-tsung Shih-lu*, 2]

- 2 April 1577 AD

"... At the 3rd mark in the central half of *ch'ou*, the Moon was eclipsed. It was total."
[*Ming-shih-lu*, 60]

- 23 March 1578 AD

"... That night, at the 3rd mark in the central half of *hsu*, the Moon was eclipsed."
[*Ming-shih-lu*, 72]

- 24 March 1587 AD

  "On the night of the full Moon, the Moon was eclipsed $9\frac{1}{2}$ divisions ... At the 3rd mark of the central half of *hai*, it returned (to fullness.)"
  [*Ming-shih-lu*, 183]

- 22 October 1596 AD

  "... At the 2nd mark in the central half of *ssu*, the Sun began to be eclipsed. At the 4th mark of the central half of *wu*, it was eclipsed $9\frac{1}{2}$ divisions."
  [*Ming-shen-tsung Shih-lu*, 301]

- 15 December 1610 AD

  "The Sun was eclipsed $7\frac{1}{2}$ divisions. It began at the 1st mark of the central half of *wei*. The eclipse reached its maximum at the 2nd mark in the initial half of *shen*. At the 2nd mark in the initial half of *yu*, it had returned."
  [*Kuo-tsio*]

- 20 February 1617 AD

  "The Moon was eclipsed at the 2nd mark of the initial half of *hsu*. It was total. The eclipse reached its maximum at the 3rd mark of *hsu*."
  [*Han-yeh-lu*]

Appendix C

Timed Japanese Eclipse Records

These translations were made from the Japanese eclipse records collected by Kanda (1935). In a number of cases Kanda (1935) has located more than one report of an eclipses. Usually these records contain the identical details of the eclipses and so I have chosen to translate the most complete account available.

C.1 Solar Eclipses

- 2 December 875 AD

  "12th month, *keng-ch'en*. On the first day of the month, during the night the Sun should have been eclipsed at 3 marks in *ch'ou*."
  [*San-tai Shih-lu*, 27]

- 17 May 877 AD

  "Summer, 4th month, *jen-shen*. On the first day of the month, during the night the Sun should have been eclipsed at 1 mark in *ch'ou*. The loss should have begun at 3 marks and 3 *fen* in *tzu*, and (the Sun) should have been returned to fullness at 2 marks and 1 *fen* in *yin*."
  [*San-tai Shih-lu*, 31]

- 10 August 975 AD

  "The officials of the *yin-yang* office reported a great waning of the Sun on the 1st day of the 7th month, *hsin-wei*. The Sun was $\frac{4}{15}$ eclipsed. The loss should have begun at 1 mark and 3 *fen* in *mao*, as the calculated time (of the middle of the eclipse) was 2 marks and 1 *fen* in *ch'en*, and (the Sun) should have been returned to fullness at 2 fen in the initial mark of *ssu*."
  [*Chao-yeh Ch'un-tsai*, 15]

- 28 March 982 AD

  "3rd month, 1st day, *kuei-ssu*. The Sun was $\frac{7}{15}$ eclipsed. The loss should have began at 3 marks and 1 *fen* in *ch'en*, as the calculated time (of the middle of the eclipse) was 1 mark and 2 *fen* in *ssu*, and (the Sun) should have been returned to fullness at 3 marks and 3 *fen* in *ssu*. The Sun was eclipsed in agreement with the calendar."
  [*Hsiao-yu-chi*]

- 11 August 1021 AD

"7th month, 1st day, *chia-hsu*. The sky and the weather were clear, but the *yin* was not settled. The Sun was eclipsed and many calendar officials observed its course ... The Sun was $\frac{13}{15}$ eclipsed. The loss should have begun at 4 marks and 1 *fen* in *ssu*, as the calculated time (of the middle of the eclipse) was 2 marks and 2 *fen* in *hsu*, and (the Sun) should have been returned to fullness at ... [text corrupt] marks and 3 *fen* in *wei*."
[*Tso-ching-chi*]

- 11 September 1029 AD

"8th month, 1st day, *ting-hai*. (The Sun) was $14\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 mark and 3 *fen* in *mao*, as the calculated time (of the middle of the eclipse) was 1 mark and 1 *fen* in *ch'en*, and (the Sun) should have been returned to fullness at 1 mark and 2 *fen* in *ssu*."
[*Hsiao-yu-chi*]

- 14 December 1080 AD

"11th month, 1st day, *chi-ch'ou*. The Sun was a little more than $11\frac{1}{2}$ eclipsed. The loss should have begun at 1 mark and ... [text corrupt] *fen* in *ssu*, as the calculated time (of the middle of the eclipse) was 4 marks and 6 *fen* in *ch'en*, and (the Sun) should have been returned to fullness at 3 marks and 5 *fen* in *wu*. The weather in the heavens was not settled and during *ssu* (the Sun) moved into clouds and for a time the eclipse was not seen."
[*Shui-tso-chi*]

- 27 February 1085 AD

"2nd month, first day of the month, *i-ch'ou*. The Sun was a little less than $8\frac{1}{2}$ eclipsed. The loss should have begun at 1 mark and 3 *fen* in *yin*, as the calculated time (of the middle of the eclipse) was 4 marks and 9 *fen* in *yin*, and (the Sun) should have been returned to fullness at 3 marks and 10 *fen* in *mao*. The preceeding details were explained by the *yin-yang* officials."
[*Chao-yeh Ch'un-tsu*, 8]

- 11 May 1100 AD

"4th month, 1st day, *ting-yu*. The Sun was a little more than $8\frac{1}{2}$ eclipsed. The loss should have begun at 4 marks and 24 *ch'en* in *yin*, as the calculated time (of the middle of the eclipse) was 2 marks and 12 *fen* in *ssu*, and (the Sun) should have been returned to fullness at 1 *fen* in the initial mark of *mao*. The preceeding details were explained by the *yin-yang* officials."
[*Chao-yeh Ch'un-tsu*, 8]

- 27 December 1106 AD

"12th month, 1st day, *wu-wu*. That day the heavens were clear and it was observed that the Sun was eclipsed ... The loss should have begun at 2 marks and 22 *fen* in *wei*, as the calculated time (of the middle of the eclipse) was 3 marks and 36 *fen* in *wei*, and (the Sun) should have been returned to fullness at 4 marks and 26 *fen* in *wei*. (The Sun) reached a little less than $2\frac{1}{2}$ fifteenths eclipsed."
[*Yung-ch'ang-chi*]

- 22 May 1118 AD

  "5th month. First day of the month, *jen-wu*. That day the Sun may have been eclipsed, according to the calendar which was reported to the throne. It should have been a little more than $5\frac{1}{2}$ eclipsed. The loss should have begun at 3 marks and 20 *fen* in *shen*, as the calculated time (of the middle of the eclipse) was 1 mark and 29 *fen* in *yu*, and (the Sun) should have been returned to fullness at 3 marks and 39 *fen* in *yu*. Rain fell and it was not seen."
  [*Yung-ch'ang-chi*]

- 18 January 1143 AD

  "1st month, 1st day, *chi-ch'ou* ... The Sun was eclipsed. The loss should have begun at ... [text corrupt] marks in *yin*, as the calculated time (of the middle of the eclipse) was 1 mark in *mao*, and (the Sun) should have been returned to fullness at 5 marks in *mao*."
  [*T'ai-chi*, 3]

- 26 October 1147 AD

  "10th month, 1st day, *hsui-mao*. The Sun was eclipsed. An important official submitted to the throne: 'On the first day of the month, *hsui-mao*, the Sun was a little less than $10\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 4 marks and 11 *fen* in *shen*, as the calculated time (of the middle of the eclipse) was 3 marks and 5 *fen* in *yu*, and (the Sun) should have been returned to fullness at 2 marks and 14 *fen* in *hsu*'."
  [*Pen-chao Shih-chi*, 33]

- 20 April 1148 AD

  "4th month, 1st day, *wu-tzu*. The Sun was eclipsed ... That day there were heavy clouds and the eclipse was not fully seen. (The eclipse) reached a little more than $7\frac{1}{2}$ fifteenths. The loss should have begun at 4 marks and 7 *fen* in *wu*, as the calculated time (of the middle of the eclipse) was 27 *fen* in the initial mark of *wei*, and (the Sun) should have been returned to fullness at 3 marks and 19 *fen* in *wei*."
  [*Pen-chao Shih-chi*, 34]

- 10 April 1149 AD

  "3rd month, 1st day, *kuei-wei*. The Sun was eclipsed. An important official submitted to the throne: 'On the fist day of the month, *kuei-wei*, the Sun was a little less than $14\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 2 marks in *yin*, as the calculated time (of the middle of the eclipse) was 1 mark in *mao*, and (the Sun) should have been returned to fullness at 1 mark in *ch'en*'."
  [*Pen-chao Shih-chi*, 35]

- 4 September 1187 AD

  "7th month, 29th day, *wu-ch'en*. That day the Sun was eclipsed. The *yin-yang* officials reported that the loss should have begun at 1 mark in *yu* ... The middle of the eclipse was at 3 marks in *yu*."
  [*Yu-yeh*, 50]

- 13 May 1203 AD

  "4th month, 1st day, *chi-hai*. The Sun was a little more than $11\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 3 marks in *yin*, as the calculated time (of the middle of the eclipse) was 8 marks in *yin*..."
  [*Chieu-jen-san Nien-p'ei Chu-li*]

- 18 December 1210 AD

  "12th month, 1st day, *i-mao*. The Sun was $10\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 mark in *mao*, and (the Sun) should have been returned to fullness at 4 marks in *ch'en*."
  [*Ch'eng-yuan-ssu Nien-p'ie Chu-li*]

- 14 May 1230 AD

  "4th month, 1st day, *jen-hsu*. The Sun was $\frac{3}{15}$ eclipsed. The loss should have begun at 8 marks in *wu*, as the calculated time (of the middle of the eclipse) was 1 mark in *wei*, and (the Sun) should have been returned to fullness at 3 marks in *wei*."
  [*Ming-yueh-chi*]

- 25 July 1245 AD

  "7th month, 1st day. That day the Sun was eclipsed. The loss should have begun at 4 marks and 61 *fen* in *shen*, as the calculated time (of the middle of the eclipse) was 1 mark and 59 *fen* in *yu*. The eclipse should have reached a little more than $13\frac{1}{2}$ fifteenths. (The Sun) should have been returned to fullness at 1 mark and 64 *fen* in *hsu*."
  [*P'ing-hu-chi*]

- 19 January 1246 AD

  "1st month, 1st day, *hsin-mao*. That day it was observed that the Sun was eclipsed. All of the officials reported to the throne that the loss should have begun at 6 marks in *wei*, and (the Sun) should have been returned to fullness at 5 marks in *shen*."
  [*Kang-wu Kuan-pe-chi*]

- 25 May 1267 AD

  "5th month, 1st day. Before night had fallen, the Sun was eclipsed. The loss should have begun at 3 marks in *shen*, according to all of the officials. The rain cleared, but the eclipse could not be distinguished."
  [*Chi-hsuan-chi*]

- 28 November 1304 AD

  "11th month, 1st day, *chi-yu*. The Sun was eclipsed. During the hour of *ch'en* the Sun rose already eclipsed. According to the calendar, the loss should have begun at 8 marks in *yin*, as the calculated time (of the middle of the eclipse) was 5 marks in *mao*, and (the Sun) should have been returned to fullness at 3 marks in *ch'en*."
  [*Hsuan-shih Yu-ch'ao*]

- 3 April 1307 AD

  "3rd month, 1st day, *i-ch'ou*. The Sun was a little more than $10\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 5 marks and $57\frac{1}{2}$ *fen* in *shen*, as the calculated time (of the middle of the eclipse) was 4 marks and 82 *fen* in *yu*, and (the Sun) should have been returned to fullness at 4 marks and $22\frac{1}{2}$ *fen* in *hsu*."
  [*Ch'eng-yuan-ssu Nien-p'ie Chu-li*]

- 21 February 1319 AD

"2nd month, first day of the month, *ting-hai*. The previous night heavy rain fell and a great wind blew. At dawn the wind and rain stopped and the sky cleared. That day the Sun was $\frac{14}{15}$ eclipsed. The loss should have begun at 4 marks and 17 *fen* in the hour of *mao*, as the calculated time (of the middle of the eclipse) was at 4 marks and 22 *fen* in the hour of *ch'en*, and (the Sun) should have been returned to fullness at 4 marks and 27 *fen* in the hour of *ssu*, according to the honourable Doctors of Astronomy. Investigating at that time (it was seen that) the loss began during the hour of *ch'en* and it was returned to fullness during the hour of *wu*. The calendar give the eclipse as $\frac{14}{15}$, but there was only $\frac{7}{15}$ eclipsed."
[*Hua-yuan Yuan-ch'en-chi*]

- 22 February 1346 AD

"2nd month, 1st day, *keng-hsu*. Clouds covered the sky. The Sun was $\frac{10}{15}$ eclipsed. The loss should have begun at 2 marks and $2\frac{1}{2}$ *fen* in *wu*, as the calculated time (of the middle of the eclipse) was at 7 *fen* in the initial mark of *wei*, and (the Sun) should have been returned to fullness at 6 marks and $5\frac{1}{2}$ *fen* in the hour of *wei*."
[*Chen-tzu-erh Nein-p'ie Ch'un-li*]

- 5 May 1361 AD

"4th month, 1st day, *hsin-ssu*. The Sun was a little more than $\frac{1}{2}$ fifteenth eclipsed. The loss should have begun at 1 mark and 71 *fen* in the hour of *shen*, as the calculated time (of the middle of the eclipse) was at 4 *fen* in the initial mark of the hour of *yu*, and (the Sun) should have been returned to fullness at 6 marks and 49 *fen* in the hour of *yu*. At the hour that the Sun was eclipsed, the heavens were cloudy, and the eclipse was not seen."
[*Hou-yu Mei-chi*]

- 14 March 1374 AD

"2nd month, 1st day, *ting-yu*. The Sun was a little more than $12\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 4 marks and $20\frac{1}{2}$ *fen* in the hour of *ch'en*, as the calculated time (of the middle of the eclipse) was at 5 marks and 80 *fen* in the hour of *ch'en*, and (the Sun) should have been returned to fullness at 7 marks and $55\frac{1}{2}$ *fen* in the hour of *ch'en*."
[*Tung-yuan King-t'ing Jih-chi*]

- 29 August 1383 AD

"8th month, 1st day, *jen-shen*. The Sun was eclipsed. The calendar noted that (the Sun) was $\frac{4}{15}$ (eclipsed). The loss should have begun at 3 marks in the hour of *ch'en*, and (the Sun) should have been returned to fullness at 7 marks in the hour of *ch'en*. The heavens were clear and it was surprising that the eclipse was not seen when it was looked for."
[*Chi-t'ien Chia-jih Tzu-chi*]

- 27 May 1397 AD

"5th month. On the first day of the month, *jen-tzu*, the Sun was a little less than $14\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 7 marks and $78\frac{1}{2}$ *fen* in the hour of *yin*, as the calculated time (of the middle of the eclipse) was at 7 marks in the hour of *mao*, and (the Sun) should have been returned to fullness at 6 marks and $11\frac{1}{2}$ *fen* in the hour of *ch'en*."
[*Yu-chu Fa-ch'in Wang-chi*]

- 15 March 1401 AD

  "2nd month, 1st day, *keng-shen*. The heavens were clear and the Sun was eclipsed. The calendar noted that (the Sun) was a little more the $4\frac{1}{2}$ fifteenths (eclipsed). The loss should have begun at 3 marks and $49\frac{1}{2}$ *fen* in the hour of *ssu*, as the calculated time (of the middle of the eclipse) was at 5 marks and $70\frac{1}{2}$ *fen* in the hour of *ssu*, and (the Sun) should have been returned to fullness at 8 marks and 8 *fen* in the hour of *ssu*."
  [*Chi-tien Chia-jih Tzu-chi*]

- 20 September 1484 AD

  "9th month, 1st day, *i-yu*. The heavens were clear. The Sun was eclipsed. The calendar said that (the Sun) was a little less than $14\frac{1}{2}$ (eclipsed). The loss should have begun at 12 *fen* in the initial mark of the hour of *ssu*, as the calculated time (of the middle of the eclipse) was at 49 *fen* in the initial mark of the hour of *wu*, and (the Sun) should have been returned to fullness at 1 mark and 2 *fen* in the hour of *wei*."
  [*Chi-tien Chien-Chih Ching-chi*]

- 30 May 1527 AD

  "5th month, 1st day, *ting-ch'ou*. The heavens were clear. That day there was an eclipse. A little less than $7\frac{1}{2}$ fifteenths of the Sun were eclipsed. The loss should have begun at 4 marks and 71 *fen* in the hour of *ssu*, as the calculated time (of the middle of the eclipse) was at 72 *fen* in initial mark of the hour of *wu*, and (the Sun) should have been returned to fullness at 5 marks and $60\frac{1}{2}$ *fen* in the hour of *wei*."
  [*Chien-pieh-chi*]

C.2 Lunar Eclipses

- 24 August 937 AD

  "7th month, 16th day, *ping-yu*. The weather was clear. The Moon was eclipsed from 1 mark in *hai* to 3 marks in *ch'ou*."
  [*Jih-pen Chi-lioh*, 2]

- 17 February 938 AD

  "Lunar eclipse during the *Tien-sou* period, 1st year, 1st month, 16th day ... From the 2nd mark in *yu* to the 1st mark in *hsu* the Moon was eclipsed."
  [*Yuan-t'ai-li*]

- 8 January 939 AD

  "... That year, 12th month, 16th day, *wu-tzu*. During the night, the Moon may have been a little more than $4\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 *fen* (in the initial mark) of *hai*, as the calculated time (of the middle of the eclipse) was 1 mark, 2 *fen* in *hai*, and the Moon was returned to fullness at 2 marks, 4 *fen* in *hai*."
  [*Pen-chao Shih-chi*]

- 29 December 1023 AD

"11th month, 14th day, *chia-ch'en*. The Moon was completely eclipsed. The loss should have begun at ... [text corrupt] marks, 1 *fen* in *yin*, as the calculated time (of the middle of the eclipse) was 2 marks, 2 *fen* in *yu*, and (the Moon) was returned to fullness at 3 marks, 3 *fen* in *mao*. At that hour it rained. At the end of the night, the heavens cleared and the Moon was clearly seen. This eclipse was taken from the calendar."

[*Hsiao-yu-chi*]

- 18 October 1027 AD

"9th month, 16th day, *kuei-ch'ou*. The Moon was eclipsed. Surprisingly, the calendar had not noted this, but rather (had predicted the eclipse) for the next day instead. This example was used in evidence by the instructors as by daytime they could not avoid reporting the eclipse. The Master Cheng-chou said that as this was a day-time eclipse it was not noted (correctly). The collator (of the records) wrote that the Moon was completely eclipsed. The loss should have begun at 3 marks, 30 *fen* in *wu*, as the calculated time (of the middle of the eclipse) was 2 marks, 8 *fen* in *wei*, and (the Moon) was returned to fullness at 1 mark, 2 *fen* in *yu*."

[*Hsiao-yu-chi*]

- 6 October 1028 AD

"9th month, 16th day, *ting-wei*. The heavens were clear. The Moon was a little more than $6\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 3 marks in *yu*, as the calculated time (of the middle of the eclipse) was 7 marks, 39 *fen* in *yu*, and (the Moon) was returned to fullness at 3 marks, in *hsu*."

[*Tsan-ching-chi*]

- 30 January 1078 AD

"Intercalary 12th month, 14th day, *keng-shen*, night of the full Moon. The Moon was completely eclipsed. The loss should have begun at 2 marks, 10 *fen* in *ch'ou*, as the calculated time (of the middle of the eclipse) was 3 marks, 7 *fen* in *yin*, and (the Moon) was returned to fullness at 4 marks, 8 *fen* in *wei*. That night snow fell and by morning the ground was white."

[*Shui-tsan-chi*]

- 29 November 1080 AD

"10th month, 16th day, *chia-hsu*. The Moon was a little more than $11\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 4 marks, 2 *fen* in *ch'ou*, as the calculated time (of the middle of the eclipse) was 3 marks, 10 *fen* in ... [text corrupt], and (the Moon) was returned to fullness at 2 marks, 9 *fen* in *mao*. The weather was clear and after a while it was indeed seen to be eclipsed."

[*Shui-tsan-chi*]

- 19 November 1081 AD

"10th month, 16th day, *chi-ssu*, night of the full moon. During the night rain fell. It stopped during the hour of *ssu*. That day the Moon was eclipsed. It was total. The loss should have begun at 2 marks in *wu*, as the calculated time (of the middle of the eclipse) was 3 marks in *wei*, and (the Moon) was returned to fullness at 4 marks in *shen*."

[*Shui-tsan-chi*]

- 24 April 1092 AD

"15th day, *wu-hsu*. The Moon was completely eclipsed. The loss should have begun at 1 mark, 9 *fen* in *hai*, as the calculated time (of the middle of the eclipse) was 2 marks, 10 *fen* in *tzu*, and (the Moon) was returned to fullness at 3 marks, 7 *fen* in *ch'ou*. The weather was clear."
[*Hou-erh T'iao-shih T'ung-chi*]

- 14 April 1093 AD

"3rd month, 16th day, *kuei-ssu*. The Moon was a little less than $7\frac{1}{2}$ eclipsed. The loss should have begun at 2 marks, 2 *fen* in *wei*, as the calculated time (of the middle of the eclipse) was 1 marks, 4 *fen* in *shen*, and (the Moon) was returned to fullness at 4 marks, 6 *fen* in *shen*. The weather was clear (but) it was not seen."
[*Hou-erh T'iao-shih T'ung-chi*]

- 30 January 1097 AD

"1st month, 15th day, *keng-tzu*, full moon. At dusk there was an eclipse of the Moon. It was a little more than $6\frac{1}{2}$ fifteenths (eclipsed). The loss should have begun at 2 marks and 10 *fen* in the hour of *hsu*, as the calculated time (of the middle of the eclipse) was at 4 marks and 10 *fen* in the hour of *hsu*, and (the Moon) should have been returned to fullness at 2 marks and 5 *fen* in the hour of *hai*. The Moon should have moved within *hsing*."
[*Shen-yu-chi*]

- 18 October 1111 AD

"9th month, 14th day. That night the Moon was $9\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 4 marks and 14 *fen* in *tzu*, as the calculated time (of the middle of the eclipse) was 3 marks and 11 *fen* in *ch'ou*, and (the Moon) should have been returned to fullness at 3 marks and 10 *fen* in *yin*. The end of the eclipse had already been noted by the calendar before it was fully seen."
[*Shen-yu-chi*]

- 5 June 1118 AD

"5th month, 15th day, *ping-shen*. That evening the Moon was $12\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 mark, 17 *fen* in *hsu*, as the calculated time (of the middle of the eclipse) was 16 *fen* in the initial mark of *hai*, and (the Moon) should have been returned to fullness at 4 marks, 7 *fen* in *hai*. The Moon was seen to be completely eclipsed."
[*Shen-yu-chi*]

- 27 May 1127 AD

"4th month, 15th day, *chia-hsu*. In the morning the rain stopped and the heavens were clear. That evening, the Moon was eclipsed. The Chief official of the *yin-yang* office announced in the morning that (the eclipsed reached) a little less than $7\frac{1}{2}$ fifteenths. The loss should have begun at 1 mark in *hsu*, as the calculated time (of the middle of the eclipse) was 4 marks in *hsu*, and (the Moon) should have been returned to fullness at 1 mark in *hai*. In the evening there was a little rain. As night fell the clouds cleared and the Moon was seen to be eclipsed."
[*Shen-yu-chi*]

- 17 August 1133 AD

  "7th month, 15th day. The heavens were clear. That night the Moon was a little less than $7\frac{1}{2}$ fifteenths eclipsed. The Moon was in the lodge *wei*. The loss should have begun at 3 marks, 78 *fen* in *wei*, as the calculated time (of the middle of the eclipse) was ... [text corrupt] marks, 13 *fen* in *tzu*, and (the Moon) should have been returned to fullness at 32 *fen* in the initial mark of *ch'ou*."
  [*Shen-yu-chi*]

- 17 June 1155 AD

  "5th month, 16th day, *jen-hsu* ... The loss should have begun at 3 marks, 12 *fen* in *yin*, as the calculated time (of the middle of the eclipse) was 3 marks, 20 *fen* in *yin*, and (the Moon) should have been returned to fullness at 4 marks, 10 *fen* in [*yin*]."
  [*Shan-huai-chi*]

- 8 August 1161 AD

  "7th month, 14th day, *i-yu*. The heavens were clear. That night the Moon was eclipsed. The loss should have begun at 16 *fen* in the initial mark of *ch'ou*, as the calculated time (of the middle of the eclipse) was 3 marks, 9 *fen* in *yin*, and (the Moon) should have been returned to fullness at 5 marks, 32 *fen* in *mao*."
  [*Shan-huai-chi*]

- 6 April 1167 AD

  "3rd month, 15th day, *kuei-ch'ou*. The Moon was eclipsed ... The loss should have begun at 72 *fen* in the initial mark of *shen*, as the calculated time (of the middle of the eclipse) was 6 marks, 79 *fen* in *shen*, and (the Moon) should have been returned to fullness at 5 marks, 62 *fen* in *yu*."
  [*Shan-huai-chi*]

- 15 March 1169 AD

  "... That month, 15th day, night of the full Moon. At dawn, the Moon was eclipsed. The Moon was $\frac{8}{15}$ eclipsed. The eclipse should have begun at 2 marks, 9 *fen* in *yin*, as the calculated time (of the middle of the eclipse) was 7 marks in *yin*, and (the Moon) should have been returned to fullness at 3 marks in *mao*."
  [*Ping-fan-chi*]

- 28 April 1203 AD

  "3rd month, 15th day, *chia-shen*, night of the full Moon. The Moon was a little less than $8\frac{1}{2}$ eclipsed. The loss should have begun at 3 marks in *yin*, as the calculated time (of the middle of the eclipse) was 1 mark in *mao*, and (the Moon) should have been returned to fullness at 7 marks in *mao*."
  [*Chien-jen San-nien-chu Chu-li*]

- 22 October 1203 AD

  "9th month, 16th day, *hsin-ssu*, night of the full Moon. The Moon was a little less than $9\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 mark in *wei*, as the calculated time (of the middle of the eclipse) was 7 marks in *wei*, and (the Moon) should have been returned to fullness at 1 mark in *shen*."
  [*Chien-jen San-nien-chu Chu-li*]

- 2 December 1210 AD

"11th month, 15th day, *chia-hai*. The Moon was more than $\frac{8}{15}$ eclipsed. The loss should have begun at 8 marks in *shen*, and (the Moon) should have been returned to fullness at 1 mark in *hsu*."

[*Shui-yuan Ssu-nien-chu Chu-li*]

- 10 November 1212 AD

"16th day. The Moon was eclipsed. The loss should have begun at 7 marks, $12\frac{1}{2}$ *fen* in *hai*, as the calculated time (of the middle of the eclipse) was 5 marks, 14 *fen* in *tzu*, and (the Moon) should have been returned to fullness at 2 marks, $35\frac{1}{2}$ *fen* in *ch'ou*. The Moon was a little more than $9\frac{1}{2}$ fifteenths eclipsed."

[*Yung-chiu Wu-nien Ch'ing-yu Ching-fa-chi*]

- 1 November 1221 AD

"10th month, 16th day, *ping-yin*, night of the full Moon. The Moon was a little more than $8\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 mark, $80\frac{1}{2}$ *fen* in *hai*, as the calculated time (of the middle of the eclipse) was 6 marks, 67 *fen* in *hai*, and (the Moon) should have been returned to fullness at 3 marks, $25\frac{1}{2}$ *fen* in *tzu*."

[*Yung-chiu San-nien-chu Chu-li*]

- 27 April 1222 AD

"3rd month, 15th day, *kuei-hai*, night of the full Moon. The Moon was eclipsed. It was complete and total. The loss should have begun at 39 *fen* in the initial mark of *shen*, as the calculated time (of the middle of the eclipse) was 2 marks, 19 *fen* in *yu*, and (the Moon) should have been returned to fullness at 4 marks, 41 *fen* in *hsu*."

[*Yung-chiu Ssu-nien-chu Chu-li*]

- 14 February 1226 AD

"1st month, 16th day, *jen-shen* ... night of the full Moon. The Moon was completely eclipsed. The loss should have begun at 6 marks, 10 *fen* in *mao*, as the calculated time (of the middle of the eclipse) was 8 marks, $15\frac{1}{2}$ *fen* in *mao*, and (the Moon) should have been returned to fullness at 1 mark, 77 *fen* in *ssu*."

[*Chia-wu Erh-nien-chu Chu-li*]

- 17 May 1231 AD

"4th month, 14th day, *keng-wu*. The Moon was eclipsed. The loss should have begun at 7 marks, in *ch'ou*, and (the Moon) should have been returned to fullness at 1 mark, in *tzu*. It is stated that it was not visible."

[*Wu-ch'i-ching*, 27]

- 27 March 1233 AD

"2nd month, 15th day, *keng-yui*, night of the full Moon. The Moon was completely eclipsed. The loss should have begun at 6 marks, 41 *fen* in *yu*, as the calculated time (of the middle of the eclipse) was 7 marks, 22 *fen* in *hsu*, and (the Moon) should have been returned to fullness at 8 marks, 3 *fen* in *hai*."

[*Chen-yung Erh-nien-chu Chu-li*]

- 7 May 1240 AD

  "4th month, 10th day, *wu-shen*. The heavens were overcast. That night the Moon was eclipsed. The loss should have begun at 5 marks, 81 *fen* in *tzu*, as the calculated time (of the middle of the eclipse) was 7 marks, 61 *fen* in *ch'ou*. The eclipse was fully total. (The Moon) should have been returned to fullness at 1 mark, 13 *fen* in *mao*."

  [*P'ing-hu-chi*]

- 25 February 1244 AD

  "1st month, 16th day, *ting-ssu*. The heavens were overcast. The calendar said that the Moon was eclipsed. The loss should have begun at 8 marks, $28\frac{1}{2}$ *fen* in *wei*, as the calculated time (of the middle of the eclipse) was ... [text corrupt] marks, 29 *fen* in *yu*, and (the Moon) should have been returned to fullness at 4 marks, $12\frac{1}{2}$ *fen* in *hsu*."

  [*Miao-huai-chi*]

- 13 February 1245 AD

  "1st month, 15th day, *hsin-hai*. The weather was not settled. That night the minister said that the Moon was eclipsed ... The loss should have begun at 2 marks, 7 *fen* in *yu*, as the calculated time (of the middle of the eclipse) was 71 *fen* in the initial mark of *hsu*. The eclipse reached a little more than $8\frac{1}{2}$ fifteenths. (The Moon) should have been returned to fullness at 5 marks, 58 *fen* in *hsu*."

  [*P'ing-hu-chi*]

- 9 August 1245 AD

  "7th month, 16th day, *wu-shen*. That night the Moon was eclipsed. The loss should have begun at 1 mark in *yu*, as the calculated time (of the middle of the eclipse) was 6 marks in *yu*. The eclipse reached a little more than $8\frac{1}{2}$ fifteenths. (The Moon) should have been returned to fullness at 2 marks, 52 *fen* in *hsu*. At the start of the night the weather was cloudy and (the sky) was not clear. The night was cold. Following the beginning of the eclipse, the clouds came and despite a gap in the clouds (the eclipse) could not be seen."

  [*P'ing-hu-chi*]

- 11 July 1283 AD

  "6th month, 16th day, *we-hsu*. The weather was clear. During the night the Moon was eclipsed. The loss should have begun at 3 marks in *shen*, as the calculated time (of the middle of the eclipse) was 3 marks in *yu*, and (the Moon) should have been returned to fullness at 2 marks in *hsu*."

  [*K'an-shen-chi*]

- 29 April 1287 AD

  "3rd month, 16th day, *ping-wu*. The weather was clear. That night, the Moon was eclipsed. The loss should have begun at 4 marks in *yu*, as the calculated time (of the middle of the eclipse) was 5 marks in *hsu*, and (the Moon) should have been returned to fullness at 5 marks in *hai*."

  [*K'an-shen-chi*]

- 9 June 1294 AD

"5th month, 14th day, *chia-tzu*. The weather was clear. (According to) a study of the classic books, the Moon was eclipsed ... The loss should have begun at 3 marks in *hsu*, as the calculated time (of the middle of the eclipse) was 3 marks in *hai*, and (the Moon) should have been returned to fullness at 3 marks in *tzu*."

[*K'an-shen-chi*]

- 1 September 1308 AD

"8th month, 16th day, *jen-yin*. The Moon was eclipsed. It was seen during the hour of *hsu*. (According to) that day's calendar, the loss should have begun at 7 marks in *shen* ... [remaining text corrupt]."

[*Hsu-shih Yu-ch'ao*, 14]

- 26 January 1339 AD

"12th month, 16th day, *ping-yu*. The Moon was a little more than $9\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 7 marks and 79 *fen* in *wu*, as the calculated time (of the middle of the eclipse) was 5 marks and 29 *fen* in *wei*, and (the Moon) should have been returned to fullness at 2 marks and 63 *fen* in *shen*."

[*Ch'ien-wu Wu-nien-chu Chu-li*]

- 21 July 1339 AD

"6th month, 14th day, *jen-yin*. The Moon was a little more than $9\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 7 marks and 80 *fen* in *yu*, as the calculated time (of the middle of the eclipse) was 5 marks and 57 *fen* in *hsu*, and (the Moon) should have been returned to fullness at 3 marks and 34 *fen* in [*hai*]."

[*Li-ying Erh-nien-chu Chu-li*]

- 10 June 1340 AD

"5th month, 15th day, *ting-mao*. The Moon was a little more than $2\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 4 marks and $58\frac{1}{2}$ *fen* in *tzu*, as the calculated time (of the middle of the eclipse) was 5 marks and 56 *fen* in *tzu*, and (the Moon) should have been returned to fullness at 6 marks and $53\frac{1}{2}$ *fen* in *tzu*."

[*Li-ying San-nien-chu Chu-li*]

- 5 December 1340 AD

"11th month, 16th day, *i-ch'ou*. The Moon was a little less than $7\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 mark and 24 *fen* in *mao*, as the calculated time (of the middle of the eclipse) was 6 marks and 24 *fen* in *mao*, and (the Moon) should have been returned to fullness at 2 marks and 60 *fen* in *ch'en*."

[*Li-ying San-nien-chu Chu-li*]

- 12 September 1345 AD

"16th day, *ting-mao*. The Moon was eclipsed. It was fully total. The loss should have begun at 4 marks and $61\frac{1}{2}$ *fen* in *yu*, as the calculated time (of the middle of the eclipse) was 6 marks and 39 *fen* in *hsu*, and (the Moon) should have been returned to fullness at 8 marks and $16\frac{1}{2}$ *fen* in *hai*."

[*Wen-ho Yuan-nien-chu Chu-li*]

- 8 March 1346 AD

  "2nd month, 15th day, *chia-tzu*. The heavens were clear. The Moon was a little more than $10\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 mark and 28 *fen* in *tzu*, as the calculated time (of the middle of the eclipse) was 7 marks and 51 *fen* in *shen*, and (the Moon) should have been returned to fullness at 5 marks and 46 *fen* in *yu*."

  [*Wen-ho Erh-nien-chu Chu-li*]

- 1 September 1346 AD

  "8th month, 15th day, *hsin-yu*. The Moon was a little less than $11\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 2 marks and 1 *fen* in *tzu*, as the calculated time (of the middle of the eclipse) was 1 mark and 21 *fen* in *ch'ou*, and (the Moon) should have been returned to fullness at 41 *fen* in the initial mark of *ch'ou*."

  [*Wen-ho Erh-nien-chu Chu-li*]

- 1 July 1349 AD

  "6th month, 15th day, *i-hai*. The Moon was eclipsed. It was fully total. The loss should have begun at 1 mark and 73 *fen* in *yin*, as the calculated time (of the middle of the eclipse) was 2 marks and 69 *fen* in *mao*, and (the Moon) should have been returned to fullness at 3 marks and 65 *fen* in *ch'en*."

  [*Wen-ho Ssu-nien-chu Chu-li*]

- 27 February 1355 AD

  "1st month, 15th day, *jen-yin*. The Moon was a little less than $8\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 6 marks and $8\frac{1}{2}$ *fen* in *wei*, as the calculated time (of the middle of the eclipse) was 2 marks and 46 *fen* in *shen*, and (the Moon) should have been returned to fullness at 7 marks and $27\frac{1}{2}$ *fen* in *shen*."

  [*Wen-ho Ssu-nien-chu Chu-li*]

- 23 August 1355 AD

  "7th month, 15th day, *chi-hai*. The Moon was a little more than $7\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 2 marks and $69\frac{1}{2}$ *fen* in *hsu*, as the calculated time (of the middle of the eclipse) was 7 marks and 63 *fen* in *hsu*, and (the Moon) should have been returned to fullness at 4 marks and $28\frac{1}{2}$ *fen* in *hai*."

  [*Wen-ho Ssu-nien-chu Chu-li*]

- 17 February 1356 AD

  "1st month, 16th day, *ting-yu*. The Moon was eclipsed. It was completely eclipsed. The loss should have begun at 5 marks in *yin*, as the calculated time (of the middle of the eclipse) was 6 marks in *mao*, and (the Moon) should have been returned to fullness at 7 marks in *ch'en*."

  [*Wen-ho Wu-nien-chu Chu-li*]

- 11 June 1359 AD

  "5th month, 15th day, *ting-wei*. The Moon was ... [text corrupt] eclipsed. The loss should have begun at 5 marks in *tzu*, as the calculated time (of the middle of the eclipse) was 3 marks in *ch'ou*, and (the Moon) should have been returned to fullness at 3 marks in *yin*."

  [*Yen-wen Wu-nien-chu Chu-li*]

- 5 December 1359 AD

"11th month, 15th day, *chia-ch'en*. The Moon was eclipsed. It was fully total. The loss should have begun at 5 marks in *wei*, as the calculated time (of the middle of the eclipse) was 7 marks in *shen*, and (the Moon) should have been returned to fullness at 4 marks in *hsu*."

[*Yen-wen Wu-nien-chu Chu-li*]

- 30 March 1363 AD

"2nd month, 15th day, *i-mao*. The heavens were clear. The Moon was eclipsed. It was fully total. The loss should have begun at 7 marks and 6 *fen* in *wu*, as the calculated time (of the middle of the eclipse) was 1 mark and 8 *fen* in *shen*, and (the Moon) should have been returned to fullness at 1 marks in *yu*."

[*Shih-shou-chi*, 32]

- 18 March 1364 AD

"12th month, 14th day, *chi-yu*. The heavens were overcast. During *ssu* heavy rain fell. During *wu* it did not cease raining ... That night the Moon was eclipsed. At that time it was not visible. The Moon was a little more than $11\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 52 *fen* in the initial mark of *tzu*, as the calculated time (of the middle of the eclipse) was 7 marks and 34 *fen* in *shen*, and (the Moon) should have been returned to fullness at 5 marks and 72 *fen* in *ch'ou*."

[*Shih-shou-chi*, 35]

- 12 September 1364 AD

"8th month, 16th day, *ting-wei*. The heavens were overcast. From the hour of *mao* the rain came down. All day it did not stop. When night descended, the rain (continued to) fall. That night the Moon was eclipsed. It reached a little more than $11\frac{1}{2}$ fifteenths. The loss should have begun at 5 marks and 2 *fen* in *mao*, as the calculated time (of the middle of the eclipse) was 4 marks and 22 *fen* in *ch'en*, and (the Moon) should have been returned to fullness at 3 marks and 42 *fen* in *ssu*."

[*Shih-shou-chi*, 40]

- 16 January 1367 AD

"12th month, 16th day, *kuei-hai*. The heavens were clear. That night the Moon was eclipsed. It was fully total. The loss should have begun at 3 marks and 8 *fen* in *ch'ou*, as the calculated time (of the middle of the eclipse) was 5 marks and 14 *fen* in *yin*, and (the Moon) should have been returned to fullness at 7 marks and 19 *fen* in *mao*."

[*Chi-t'ien Chia-jih T'zu-chi*]

- 12 July 1367 AD

"6th month, 15th day, *keng-shen*. The heavens were clear but dark. That day the Moon was eclipsed ... It was fully total. The loss should have begun at 5 marks and 49 *fen* in *wu*, as the calculated time (of the middle of the eclipse) was 6 marks and 45 *fen* in *wei*, and (the Moon) should have been returned to fullness at 7 marks and 41 *fen* in *shen*."

[*Shih-shou-chi*, 46]

• 27 February 1374 AD

"1st month, 16th day, *jen-wu*. The Moon was totally eclipsed. The loss should have begun at 6 marks and 13 *fen* in *wei*, as the calculated time (of the middle of the eclipse) was 6 marks and 79 *fen* in *shen*, and (the Moon) should have been returned to fullness at 7 marks and 59 *fen* in *wei*. The heavens were clear. That day the Moon was eclipsed."
[*Tung-yuan Kung-t'ing Jih-chi*]

• 27 February 1393 AD

"1st month, 16th day. The Moon was eclipsed. It reached a little more than $10\frac{1}{2}$ fifteenths. The loss should have begun at 77 *fen* in the initial mark of *ch'ou*, as the calculated time (of the middle of the eclipse) was 7 marks and 1 *fen* in *shen*, and (the Moon) should have been returned to fullness at 5 marks and 3 *fen* in *yu*."
[*Ming-te Ssu-nien-chu Chu-li*]

• 4 December 1397 AD

"11th month, night of the full Moon, *chi-yu*, 15th day. The Moon was eclipsed. It reached a little more than $2\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 marks and $70\frac{1}{2}$ *fen* in *mao*, as the calculated time (of the middle of the eclipse) was 2 marks and 60 *fen* in *mao*, and (the Moon) should have been returned to fullness at 3 marks and $3\frac{1}{2}$ *fen* in *mao*."
[*Yun-chu Fa-ch'in Jen-chi*]

• 30 March 1401 AD

"2nd month, 16th day, *i-hai*. The weather was clear. That day — eclipse. The loss should have begun at 5 marks in *ch'en*, and (the Moon) should have been returned to fullness at 7 marks in *ch'en*."
[*Ying-yang-chi*]

• 22 September 1401 AD

"8th month, 15th day, *hsin-wei*. The Moon was eclipsed. At 1 mark and 51 *fen* in *tzu* it should have begun, and (the Moon) should have been returned to fullness at 5 marks and 77 *fen* in *tzu*. That night there were no clouds, but the eclipse was not visible..."
[*Ying-yang-chi*]

• 22 July 1404 AD

"6th month, 15th day, *i-yu* ... The Moon was a little more than $9\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 5 marks and 66 *fen* in *hai*, as the calculated time (of the middle of the eclipse) was 3 marks in *tzu*, and (the Moon) should have been returned to fullness at $17\frac{1}{2}$ *fen* in the initial mark of *ch'ou*."
[*Ying-yang Shih-i-nien-chu Chu-li*]

• 22 May 1407 AD

"4th month, 15th day, *chi-hai*. The weather was clear. The Moon was completely eclipsed. The loss should have begun at 11 *fen* in the initial mark of *mao*."
[*Ying-yang Shih-i-nien-chu Chu-li*]

- 2 September 1411 AD

  "8th month, 14th day, *kuei-mao*. The Moon was eclipsed. It reached a little more than $3\frac{1}{2}$ fifteenths. The loss should have begun at ... [text corrupt] marks and 5 *fen* in *ch'ou*, as the calculated time (of the middle of the eclipse) was 6 marks and 57 *fen* in *ch'ou*, and (the Moon) should have been returned to fullness at 25 *fen* in the initial mark of *yu*."
  [*Ying-yang Shih-pa-nien-chu Chu-li*]

- 26 January 1423 AD

  "12th month, 14th day, *ting-mao*. The Moon was a little less than $2\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 79 *fen* in the initial mark of *mao*, as the calculated time (of the middle of the eclipse) was 2 marks and 4 *fen* in *mao*, and (the Moon) should have been returned to fullness at 3 marks and 11 *fen* in *mao*."
  [*Chien-hsuan Kung-chi*, 6]

- 23 September 1428 AD

  "8th month, 14th day, *chia-wu*. The Moon was $\frac{14}{15}$ eclipsed. The loss should have begun at 2 marks and 38 *fen* in *ch'ou*, as the calculated time (of the middle of the eclipse) was ... [text corrupt], and (the Moon) should have been returned to fullness at 2 marks and 38 *fen* in *mao*. The heavens were overcast. From the end of the evening rain fell..."
  [*Sa-chia-chi*]

- 13 June 1432 AD

  "6th month, 16th day. That night the Moon was eclipsed during the initial half of *hai*. The calendar noted that the loss should have begun at $62\frac{1}{2}$ *fen* in the initial mark of *yu*, as the calculated time (of the middle of the eclipse) was 2 marks and 40 *fen* in *hsu*, and (the Moon) should have been returned to fullness at 4 marks and $17\frac{1}{2}$ *fen* in *hai* ..."
  [*Man-chi Chun-hou Jih-chi*]

- 12 March 1438 AD

  "2nd month, 16th day. The heavens were clear. That day the Moon was eclipsed. The loss should have begun at 3 marks in *yin* ..."
  [*Shih-hsiang-chi*, 10]

- 15th October 1464 AD

  "9th month, 15th day, *i-ch'ou* ... The Moon was eclipsed. It reached a little less than $14\frac{1}{2}$ fifteenths. The loss should have begun at 7 marks and 6 *fen* in *shen*, as the calculated time (of the middle of the eclipse) was 34 *fen* in the initial mark of *hsu*, and (the Moon) should have been returned to fullness at 1 mark and 54 *fen* in *hai*."
  [*K'uan-cheng Wu-nien-chu Chu-li*]

- 18 January 1478 AD

  "12th month, 15th day, *wu-shen* ... The Moon was a little less than $6\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 7 marks and $47\frac{1}{2}$ *fen* in *tzu*, as the calculated time (of the middle of the eclipse) was 3 marks in *ch'ou*, and (the Moon) should have been returned to fullness at 6 marks and $64\frac{1}{2}$ *fen* in *ch'ou*."
  [*Chien-hsien Ch'ing-chi*]

- 4 October 1484 AD

"9th month, 15th day, *chi-hai*. The heavens were clear ... The calendar noted that the Moon was a little more than $4\frac{1}{2}$ fifteenths eclipsed. The loss should have begun at 1 mark and 37 *fen* in *hai*, as the calculated time (of the middle of the eclipse) was 3 marks and 63 *fen* in *hai*, and (the Moon) should have been returned to fullness at 6 marks and 5 *fen* in *hai* ..."
[*Chi-t'ien Chien-chih Hsian-chi*]

- 1 March 1485 AD

"2nd month, 15th day, *ting-mao*. The Moon was eclipsed. That day's calendar (noted that) it reached a little less than $6\frac{1}{2}$ fifteenths. The loss should have begun at 4 marks and 75 *fen* in *yu*, as the calculated time (of the middle of the eclipse) was 71 *fen* in the initial mark of *tzu*, and (the Moon) should have been returned to fullness at 5 marks and 13 *fen* in *tzu*."
[*Hsu-fa Hsing-yuan Cheng-chia-chi*, 10]

- 24 June 1526 AD

"5th month, 15th day, *ting-yu*, night of the full Moon. The Moon was completely eclipsed. The loss should have begun at 2 marks in *yu*, and (the Moon) should have been returned to fullness at 4 marks *hai*. This was taken from the calendar."
[*Chien-pieh-chi*]

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